The dairy control and management system in the robotic milking farm

S. Devir
Propositions

1. The use of a milking robot merely to free the farmer from the technical procedure of attaching teat cups does not exploit to the full the robot's real potential in the dairy.  
   *this thesis*

2. While the industry has invested in recent years a lot of effort in developing techniques for robotic milking, the development and validation of a re-shaped management concept and tools are still at an early stage.  
   *this thesis*

3. The daily capacity of the milking robot should be measured in terms of number of milkings rather than number of cows in the herd.  
   *this thesis*

4. Individual milking frequency can be used as an additional and efficient tool in the control of milk production.  
   *Maltz and Metz, 1994*

5. Tracing the cows' behavioural pattern by the number of visits to different sites in the barn can be used as an additional factor to improve management decisions.

6. The individual cow management approach allows us to handle each cow as a production unit on the one hand and as a living creature with its own needs on the other.

7. The continuous monitoring of individual data, its analysis and presentation increase the detection sensitivity of irregularities in cows' condition and performance and therefore, strengthen the contact between the herdsman and the cow.

8. The fact that more and more promising research topics being conducted at the universities and research institutes are financed by the private sector may slow down the transfer of know-how.

9. When presenting the performance of a system developed by him, the scientist would always stress that research and development is still needed. However, if the same system is presented by a salesman the audience might get the impression that it is the perfect one.
The dairy control and management system in the robotic milking farm
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The dairy control and management system in the robotic milking farm

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Abstract

The control and management system in the milking robot milking farm
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The research and development described in this thesis was directed towards the technical and managerial integration of the milking robot into the dairy farm. First a concept and tools for the milking robot dairy farm were developed. A set of parameters was introduced which represents the individual cow's production and behaviour pattern in addition to herd and automatic milking system capacity characteristics. Then, a series of three field tests was conducted to validate the automatic milking system management concept, and the tools for its implementation. The aim was to assign an individual milking frequency and concentrates supplementation regime to each dairy cow in a loose housing system. Attention was focused on the implementation of an individual production and behaviour-based strategy, using cow traffic, milking frequency and individual concentrates allocation as the control tools. In all field tests, the milking robot was available for milking and concentrates allocation for 24 hours a day. The cows visited voluntarily a selection unit which was installed before the milking robot, where an on-line milking and concentrates allocation decision was made. In the first and second field tests, cows were milked between two to five times daily, based on daily fixed and pre-determined milking frequency and concentrates allocation. In the third field test the daily milking frequency, two to six times daily, and concentrates allocation were based on frequent evaluation of cow behaviour and production performance. The methods and results described can be used as management guidelines for the loose housing milking robot dairy farm.


The work for this thesis was accomplished in: Livestock Engineering Department, DLO Institute of Agricultural and Environmental Engineering IMAG-DLO, P.O.Box 43, 6700 AA, Wageningen, The Netherlands.
Foreword

This thesis is a product of the automatic milking system project conducted at the Institute of Agricultural and Environmental Engineering, IMAG-DLO, Wageningen, The Netherlands. The project was carried out with the cooperation of many other colleagues to whom I would like to express my sincere thanks.

First of all I would like to thank Ir. A.A. Jongebreur. The success of this project owes much to his full support throughout my time at IMAG-DLO.

I would also like to thank my supervisors Prof. Dr. Ir. J.A. Renkema from the Department of Farm Management, Wageningen Agricultural University, and Prof. Dr. J.P.T.M. Noordhuizen from the Livestock Husbandry Department, Wageningen Agricultural University. Their ability to extract precise statements from the ambiguous and vague elements in my papers showed me the way forward to a successful completion of my thesis within a narrow time schedule.

The person who was my "spiritual father", stood at my side all the time and helped me to navigate my Israeli way of working and thinking through the canals of the Dutch culture is dr. Ir. J.H.M. Metz. I owe a great deal of the success of my thesis to his full support, and the way he believed in me and in my ideas, sometimes in contradiction to his own colleagues.

I received excellent assistance from Ir. A. Keen, the statistician, who was patient with me and with my frequent "urgent" problems.

Thanks also to all my colleagues in the Livestock Engineering Department of IMAG-DLO. Special thanks to the team of the experimental farm "De Vijf Roeden" in Duiven, for their cooperation sometimes at unsocial hours. Sincere thanks also to Franse Ettema who was always there to help me, despite his hidden anxiety about the effects on the cows of my controversy ideas.

I would also like to thank the IMAG-DLO technical team, led by Dolf Smits, co-ordinator of the project, who all devoted much more time to the project than was expected. From my former department, I would like to thank Mr. J. Cornelissen. From the Information and Statistics Department in IMAG-DLO I would like to thank Rijn Bijkerk and Hans Janssen especially.

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Chapter 1

General introduction

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1. Introduction

Milking robots are being developed and sold in a number of countries in Europe (Ipema et al., 1992; Dalebout, 1993; Rossing et al., 1994). More than 30 commercial milking robots have been installed in commercial and experimental dairies all over the world (Devir, 1995). The milking robot was developed to replace the manual work involved in cluster attachment in the conventional milking parlour or to replace the milking parlour itself (Ipema et al., 1992; Sonck and Donkers, 1995). However, the integration of the milking robot into the dairy farm opens up more possibilities in the development of dairy farm management.

Until now, nutrition has been the main mean of controlling production. The milking robot now offers the opportunity to use individual milking frequency as an additional tool. Appropriate barn lay-out and controlled cow traffic routine ensure that each cow can be milked voluntarily, according to her rhythm, without any human involvement. New technology enables increasingly more individual on-line data to be acquired and processed. Expert systems can then analyze such performance data for each cow and implement appropriate management decisions accordingly (Maltz and Metz, 1994).

All the above enables us to control production and make it more efficient by implementing decisions on milking, concentrates allocation and cow traffic on an individual basis. We can therefore refer to the system as an automatic milking system rather than a milking robot.

The integration of the milking robot into the dairy farm is still at an early stage. The hypothesis that cows voluntarily visit a milking robot throughout the day over a longer period has not yet been tested (Mottram, 1992). No fully-integrated management solution for the automatic milking system has been tested, validated or reported either by the milking robot companies or by any research institute.

2. Objectives of the study

The objective of this thesis research is to fill the gap between the milking robot, which is already a commercial product, and the fully-automatic control and management concept and tools which are currently not available.

A fully integrated dairy control and management system for the loose housing dairy, using a milking robot, was developed and validated in three field tests. The system described in this thesis offers a management solution for a loose housing dairy of up to 80 cows where no grazing management is applied. The experience gained from the field tests may also contribute to the integration of the milking robot into larger dairies, with or without grazing management.
3. Background

This research project was conducted under the research programme "Integration of innovative technologies in dairy farming" of the Agricultural Research Department of the Netherlands (DLO-NL). The thesis research project was carried out at the Division of Buildings and Environmental Technology of the DLO Institute of Agricultural and Environmental Engineering (IMAG-DLO), Wageningen, The Netherlands. The tests under field circumstances were conducted at the IMAG-DLO experimental dairy farm, "De Vijf Roeden", Duiven, The Netherlands.

The research is also a part of the Eureka Project "CIMIS" (Complete Integrated Milking System), a cooperation between Dutch and French research and development institutes and industries.

The expert-system for the individual concentrates supplementation and milking frequency is a joint development of IMAG-DLO and the Israeli Research Organization, ARO, the Volcani center, Bet-Dagan, Israel.

4. Outline of the thesis

Chapter 2 describes the automatic milking system management concept and tools. This chapter discusses the need for operational and process control adapted to the automatic milking system dairy environment, in which the heart of the management concept is an individual approach based on each cow's performance. Chapter 3 describes the first short-term fully integrated field test. The aim was to test the feasibility of individual parameter decisions for on-line control of milking and concentrates supply. The milking robot was available for 24 hours a day, based on voluntary cow visits to the automatic milking system. Chapter 4 describes the second field test. Here the aim was to maximize the automatic milking system capacity, under high and different milking frequency strategy, all controlled by a new version of the dairy control and management system. Another aim was to observe and analyze the cows' behaviour under the milking and concentrates supplementation routine used. Chapters 5 and 6 describe the management and production aspects respectively of a seven month field test. The aim was to assign automatically a pre-determined milking frequency and an individual concentrates supplementation regime using two management concepts. The first concept was based on a fixed milking frequency and feeding routine according to usual Dutch practice. The second concept was the variable individual high milking frequency and concentrates allocation, which was evaluated daily using an expert-system. Chapter 7 discusses the strategic and operational aspects of automatic milking management within the scope of the thesis. Chapter 8 summarizes the main points from the three field tests in the light of the newly developed dairy control and management system. Finally, the main conclusions of this thesis are presented.
References


Chapter 2

A New Dairy Control and Management System in the Automatic Milking Farm: Basic Concepts and Components

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Abstract

The introduction of automatic milking technology, including on-line individual data acquisition and processing, requires adaptation of dairy management methods. Automatic milking systems allow the individual cow to be milked and fed according to her production performance and potential in order to achieve maximal profits with minimal resources.

Because the farmer is not actually present each time a milking or feeding decision is needed, a new generation of control and management systems has been designed to assume the short-term dairy management and operational control. The overall management control still remains with the farmer or herdsperson, who is supported by the dairy control and management system. The paper discusses the influence on dairy management of the integration of the individual automatic milking and feeding systems. Then, the concept of a dairy control and management system, which includes a decision support and expert system, is described. A prototype, which enables automatic milking and feeding routines, was developed and tested.

Key words: automatic milking, dairy management, decision support system, expert system

Abbreviation key: AMS = automatic milking system, DCMS = dairy control and management system, DMS = dairy management system, DSS = decision support system, ICS = individual concentrates supplementation

1. Introduction

Integration of the milking robotics into the dairy farm frees the farmer from the labor of milking and, with supplementary tools and adjusted management methods, leads to an automatic dairy production system in which the individual cow is an "individual production unit". New technologies enable increasingly more individual on-line data to be acquired and processed. Because each cow can be milked and fed individually according to her own rhythm and performance, production efficiency is likely to increase (Maltz et al., 1992).

Today, modern dairy farms use dairy management systems (DMS) as a support system to advise the herdsperson on the overall control of dairy management (Bywater, 1981). Dairy on-line controlled subsystems, such as individual self feeders for concentrates and automatic teat cup detachment, are usually autonomous ("stand-alone") systems.

Because the farmer is not present each time a milking or feeding decision is needed, a new generation of integrated dairy control and management systems (DCMS) has been designed. The DCMS is more than a support system to be consulted by the herdsperson. Short-term use of the DCMS should enable automatic control of the daily feeding and milking routine. For the long term, DCMS should extract from each individual cow, within the constraints of the cow's biological
and behavioural characteristics, the maximum production (milk) with the minimum resources (feed, labour, milking machine time etc.).

The current European robotic milking systems are planned to be integrated in loose housing system dairies. When zero-grazing management is used, computerized individual feeding and milking systems enable an automatic daily routine in the dairy (Richard and Mark, 1988). Under grazing management, the flexibility of the management system to cope with different milking and feeding regimes is a slightly restricted. The dairy routine can not be fully automated in this case.

Because the first five automatic milking systems (AMS) were sold commercially this year, the development of management methods and tools for the automatic milking dairy farm is a new task. Such a development must be accompanied by further field tests to provide insight into the effects and profitability of flexible individual milking and feeding routines.

This paper deals with the effects of the AMS on dairy management and dairy management supporting systems. The paper concentrates on the zero-grazing AMS approach. The first part of the paper briefly introduces the present state of dairy management functions and tools. The problems of AMS dairy management functions and tools are discussed in the second part. The third part includes a description of a DCMS prototype concept and architecture that was developed and tested at Instituut voor Mechanisatie, Arbeid en Gebouwen-Dienst Landbouwkundig Onderzoek, Wageningen, The Netherlands. The fourth part discusses some research perspectives concerning the new DCMS methods and tools.

2. Dairy management and dairy DMS

2.1. Management functions

Management can be divided into three basic functions: planning, implementation and control, which together create the management cycle (Kay, 1986). Planning provides the mode of operation to accomplish the farmer’s goals (Huirne, 1990) and can be subdivided into levels according to the planning horizon. The farmer’s long-term management and investment planning is at the strategic level (Huirne, 1990). During the tactical planning, the farmer plans the dairy management to obtain optimal results within the given or proposed farm structure (Huirne, 1990). Implementation is the execution of planned activities, and control measures performance and compares it to standards.

De Hoop (1988) suggests a modified version of the management cycle (Fig. 1). The strategic and tactical planning are included within the planning function. Strategic plans involve defining of objectives, farm organization and production alternatives, financing and risk analysis. Tactical planning may include nutrition, roughage production, health care, reproduction, milk production, cattle replacement, labor and cash flow.
The operational function contains the short-term management activities: planning, execution
(i.e., "implementation" in the management cycle described), and short-term control (Fig. 1). The
operational function involves roughage production, nutrition, health care, reproduction, milk
production, cattle replacement and cash administration (De Hoop, 1988). Within short-term
control, two types of control can be distinguished.

First is short-term process control, the examination of the performance of a process in order to
decide which actions to take (Bergstrom, 1988). Short-term process control in the dairy farm is
restricted today by autonomous subsystems based on recent microelectronics applications in the
dairy farm (Jahns and Speckmann, 1992). Short-term process control consists of five main sections
(Cobben et al., 1987): 1) nutrition, including individual concentrates and roughage feeders,
weighing and mixing wagons, and water supply; 2) production control, including milking parlors,
and weighing cows; 3) animal health control, such as mastitis and body temperature; 4) fertility,
estrus detection, and birth control; 5) environmental control, including ammonia emission and
climate.

The second type of control is short-term management control, which refers to decisions or
actions that are taken to control the evolution over time of the system being controlled. Short-
term management control involves daily feeding management based mostly on free access to
roughage at the bunk (during the non-grazing period). Roughage distribution can be manual or
computerized with controlled weighing systems (e.g., weighing and mixing wagons). Concentrate
supplementation can be integrated into the total mixed ration at the bunk or individually
supplemented through self feeder. The self feeder are located in the milking parlour or at the
feeding area. In the latter case the cows’ access to the self-feeders is voluntary. Milking routine
is fixed and is based on two or three times daily milking of all lactating cows in the milking parlor.
Milking times are usually fixed according to the farm labor constraints.

Overall control function is a medium-term control of the farm and involves measuring
performance and comparing it with standards (Huurne, 1990)(Fig. 1). The farmer uses lists of items
needing attention and periodically DMS reports to improve management decisions at the herd and
the individual cow (Maltz et al., 1992).

32.2. Management Tools

Using management systems may improve dairy profits (Lazarus et al., 1990). Farmers use DMS
combined with data processing to improve management decisions (Dale et al., 1988, Heinrichs,
1989). Most DMS used in herd management are database type (Heinrichs, 1989). The DMS produces
a wide range of reports and action and attention lists that are generally based on a growing
number of automatic on-line and off-line acquired data, such as milk yield, milk conductivity, milk
temperature, cow’s activity, body temperature, body weight, tissues impedance, concentrates
supplementation, roughage consumption, and data from external sources or databases.

Some DMS include models that combine elements of physical and financial records to advise on grassland and quota management. Others combine more models, for instance, focusing on estrus or mastitis detection, culling decisions, and fertility strategy.

Nutrition software assisting the farmer planning the cow's daily ration, such as the Dutch "Cow Model" (Hyink and Meyer, 1987), and that available from the NRC (NRC, 1989) can also be integrated. Recommendations for herd nutrition are usually based on the mean cow performance include population characteristics such as parity, calving season, and stage of lactation (Heyink and Meyer, 1987; Maltz et al., 1992). Commercial DMS provide the herdsman with more available information, but since this paper only discusses AMS management applications no further examples are given.
3. The automatic milking system dairy farm

3.1. Dairy Farm Architecture and Routine

The architecture of the AMS dairy farm is based on two main sections (Fig. 2), the AMS section and the dairy section. The AMS section is divided into two subsections.

The first, selection unit (Rossing et al., 1985; Swierstra and Smits, 1989), is combined with self feeder because cows sometimes stand up, especially to visit the feeding station (Wierenga and Hopster, 1991a). Selection unit without a self feeder is also a possible configuration. Concentrates are therefore supplemented at the self feeders in the selection unit and the milking unit. The selection unit are located near the feeding area to increase their attractiveness to the cows. When a cow enters the selection unit voluntarily, a decision is made whether to send her to be milked, or supplement her with individual concentrates supplementation (ICS) or both (Fig. 2).

Second, milking unit is also integrated with a self feeder (Rossing and Ipema, 1990). There the cow is milked automatically by the milking robot and ICS or is not milked but receives ICS. The feasibility of using the self feeder integrated with milking unit was explored by Rossing et al., (1985).

The second main section, includes the feeding and lying area. The roughage part of the ration is available to the cows at the bunk of the feeding section all day. The water trough should also be located in the feeding area or at the feeding and lying areas in the dairy section.

The AMS routine is based on voluntary visits of the cow to the selection unit. Using computer-controlled gates, the daily milking and ICS AMS dairy farm routine is fully automated except for the normal veterinary routine, maintenance, and roughage distribution at the bunk. However, the latter can also be fully automated (Ipema and Benders, 1992).

3.2. Management Functions

The AMS integration in the dairy farm influences all basic functions of the management cycle: planning, operation, and control. Management using AMS is relatively new, and each cow is an
individual decision unit. Furthermore, more decisions are made for individual cows. The effects of different milking and feeding regimens on production, health, fertility, and culling have not yet been fully explored.

As part of the strategic planning function, the target functions of the decision process should be clarified. Possible targets include automation, maximum production, labor savings or any weighted combination of these records for their economic importance. The culling strategy today is largely based on age, health, production and fertility criteria (Dijkhuizen et al., 1985). Farmer and cow welfare should not be neglected.

As a result of the tactical planning function, increased milking frequency may increase production and affect milk composition, on the one hand, and affect milking machine parameters

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Fig. 3. The short-term management and process control. The dotted arrow represents the farmer's involvement in the decision making process.
and overcrowd the milking unit on the other hand (Ipema and Metz, 1992; Van der Elst and Hillerton, 1989). Parsons (1988) used computer simulation to show that two milking unit are needed for the first 60 cows, but much more data is needed to determine the optimal economic criteria to calculate the maximum capacity of the AMS. The effects of unsuccessful adaptation to the AMS should be also considered.

Within the operational function, the two short-term controls of management and process are distinguished by two characteristics: the rapidity of decision-making and the farmer's involvement in the decision-making process (Fig. 3).

Short-term management control has to be based on the cow's individual production performance profile, such as milk quantity, quality, and composition. This profile may be changed by variation in the characteristics of the milking regimen, such as frequency of milking time, intervals between milking, and the time of each milking (Rossing and Ipema, 1990). Change in

![Diagram of the dairy control and management system: control and information flow.](image)

Fig. 4. The dairy control and management system: control and information flow.
milking frequency during lactation may increase production, but it may also cause fertility problems such as delayed postpartum resumption of ovarian cyclicity and lower conception rate (Bar-Peled et al., 1992). Relations between udder health and different milking frequencies have been reported by Waterman et al., (1983). The predefined milking and ICS decisions should be made at the individual cows, based on each cow's performance (Kroll et al., 1989) and according to the AMS routine limitations, such as milking frequency and daily distribution of visits. The farmer can exercise short-term management control, assisted by the decision support system (DSS) recommendations and reports (Fig. 3).

The short-term process control includes the feeding process. Because the cow will be supplemented with concentrates only at the selection unit or at the milking unit, daily management and control of the ICS is needed. The farmer has no direct influence on the process control. The milking and the ICS decision are taken on-line by the DSS when the cow enters the selection unit. But the farmer may influence the process decisions adjusting state variables and initial values through the DSS (Fig. 3). During the day, the milking and ICS routine is dependent on the cow's visiting pattern to the selection unit. Each cow has an individual daily rhythm (Wierenga and Hopster, 1991b). Failure of the system to maintain a consistent milking and feeding regimen for the individual cow interrupts her daily rhythm and should therefore be avoided. The demand to enter the selection unit is not constant during a 24-h period. A cow that needs to be milked, according to predefined production-based standards, might come to the selection unit according to her daily rhythm, but the selection unit may be occupied by another cow. Then, such a cow may not come again (Wierenga and Hopster, 1991b) and may fail to maintain her predetermined milking regimen. Long and unequal intervals between milkings and different milking times during the day affect milk production and food intake rates negatively (Rossing and Ipema, 1990). However, supplementation of a cow with concentrates at every visit, encouraging her for further visits, may lead to ICS surplus which is expensive and may change milk composition (Thomas and Martin, 1988) and overcondition the cow near calving.

At the overall control level, the farmer who is supported by the DSS receives information on cow performance and tries to improve the milking and ICS decisions based on that information. Then, by updating herd and individual parameters the farmer controls the overall herd management via the DCMS (Fig. 3 and 4).

3.3. Management Tools

The traditional DMS, which is only assisting the farmer, proves to be an important part of a larger on-line DCMS. The DCMS handles information acquisition and processing and control, both on-line and off-line (Fig. 4). The on-line system is fed with available information from the cow's individual sensors, such as activity, body temperature, and identification number. Individual body
weight, activity, and concentrate consumption can be acquired at the selection unit or milking unit using the appropriate devices. Individual milk data, such as milk yield, milk conductivity, and milk temperature is provided at the milking unit. Opening and closing times of the selection unit and milking unit gates, cows' identification, and the exact location of cows are essential data to maintain control of the automatic daily routine control. Information on the milking robot operation is used as well. With respect to the off-line information, archival data from the farmer's data base and data from external sources is available. The DCMS produces periodically and, at the farmer's request, reports and management recommendations. The DCMS controls on-line the selection unit and milking unit gates and the self feeder. At each cow visit to the selection unit, ICS and milking decision are made. The farmer may control off-line the daily milking and feeding routine.

All conditions that influence the cow's performance are dynamically changing. Therefore, the DCMS should follow, learn, and continuously adapt itself for each individual cow. The decision-making also involves the comparison of actual performance with standards. Comparison of performances at the individual cow level, based on the previous day's performance, is a very complicated statistical effort because of large variations that occur.

The growing amount of data collected and the need for on-line integrated analysis require different tools and techniques from those for traditional systems. The use of knowledge-based systems provides not only information but also interpretation of the available information (Hogeveen et al., 1990). There are some nonintegrated, knowledge-based systems available for use in dairy farming, but none of them deals with AMS. Because the DCMS also makes decisions, an expert system should be integrated to make the final decision. An expert system is a computer-based system that uses knowledge, facts, and reasoning techniques to solve problems that normally require human expertise (Martin and Oxman, 1988). Expert systems are able to incorporate results and knowledge from different fields and to preserve expertise (Richard and Mark, 1988; Doluschitz, 1990). It therefore becomes necessary to develop an expert system to help the milking and feeding process control (Folkerts, 1988), which can be considered a new application in dairy management. An expert system that integrates advisory and diagnostic functions enhances the possibility of complex management decisions with the assistance of an on-farm computer (Heinrichs, 1988). The expert system will assist process control by analyzing and developing alternative courses of actions, repeatedly interpreting the current situation, predicting the future, diagnosing the probable cause of anticipated problems, formulating a remedial plan, and monitoring its execution to ensure success (Lanz, 1992).
4. The dairy control and management system

4.1. Main Concept

The DCMS prototype from the Institute of Agricultural Engineering Environmental used some basic assumptions. Controlling or manipulating the cows' visiting pattern to achieve a better visit distribution during the day may be possible, using different ICS portions for each cow according to her learned and predicted visiting pattern. To achieve enhanced production, each cow must follow her predetermined milking regimen. Each cow must be supplemented according to her production performance and not according to her visiting pattern. However, each visit to the selection unit is rewarded by concentrates. Some cows may overoccupy the system and these cows will be eliminated from any ICS for some time.

A precalving adaptation period to the AMS system is highly recommended and may avoid negative effects from unsuccessful adaptation to the AMS routine during the first weeks of lactation, when production potential is built. During this period (2 to 4 wk), the cow will stay within the milking group and be supplemented with a small portion of ICS at the selection unit to assist rapid adaptation to the AMS routine. An individual gate system for roughage supplementation (Ipema and Benders, 1992) can prevent dry cows obtaining high energy ration. Thus high energy ration at the bunk is avoided to prevent overconditioning before calving. Nevertheless, some cows may not adapt to the AMS routine.

Priorities will be set for cows according to their milking regimen, visiting pattern and individual response to unrewarded visits (milking or concentrates). The DCMS must be an autonomous system driven by a personal computer to reduce the AMS hardware and software costs and to make the DCMS commercially attractive to the herdperson.

4.2. System Components

The selection unit and milking unit gates and self feeder are instructed via controllers. The controller gets its operational instructions from the computerized DCMS. The DCMS consists of three main modules (Fig. 5)

1. The DSS is a database, equipped with commercial software for ration preparation, breeding, culling strategy, such as "cow model" and NRC and a model base, containing models for analyses oriented to the AMS dairy farm. Examples for such models are individual milking and feeding regimen (production), prediction of next selection unit visit (behaviour), effects on fertility (physiology) of changing milking regimen during lactation, and prediction of a culling strategy for cows that do not adapt to the system (economy).

2. The DSS is an expert system that takes decisions based on group of criteria at the behavioral
and production performance level. Not all criteria have the same contribution to the final decision. Decision criteria include milking and ICS regimen, intervals between milking, ICS rewarded and unrewarded visits, individual and herd visiting patterns, system capacity, and effects of unrewarded visits or unequal milking intervals.

3. The DSS is an input-output interface that acquires information from the sensors and milking unit and selection unit and transfers it to the database. This interface also provides the milking unit and selection unit with expert system control information.

5. Conclusions

Automatic milking technology will be introduced in the near future in various types of dairy farms. These dairy farms differ in herd size, climate, milk quota, types of AMS and grazing management system. Appropriate management methods should therefore be developed prior to other biological and economic modifications. With the introduction of individual automatic milking techniques, on-line data acquisition and processing now place the individual cow at the center of the dairy farm. New biological models must be adapted to the new circumstances in the AMS dairy farm. Various aspects of the short- and long-term management control of the milking and feeding regimen should be optimized. Research into the effect of individual milking regimen and feeding strategies on milk production and the profitability of the herd must be accelerated. The DCMS produces a full and efficient daily automatic routine in dairies based on zero-grazing management and increased efficiency in dairies where grazing is part of the daily routine. The DCMS is a new generation of DMS that integrates short- and long-term control, using expert system to enable integration of multiple data sources and on-line analysis. At the heart of the decision-making process stands the cow as an individual production unit. Herd-specific predefined values and conditions guide the DCMS decision-making process. Because the farmer cannot be present each time a feeding or milking decision is needed, the DCMS controls the short-term management at the dairy. The farmer still exercises overall dairy control which is supported by the DCMS recommendations. The combined management tools of a highly efficient DSS and a low investment in milking robotic equipment and support systems (sensors and software) will increase
the profitability of the dairy farm and will improve quality of life for the dairy cow and the
herdsperson.

References


Chapter 3

Validation of a Daily Automatic Routine for Dairy Robot Milking and Concentrates Supply.

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Abstract

The feasibility and short term consequences of a robotic milking and concentrates supplementation routine in an automatic milking system dairy were tested. The system comprised a selection unit and a milking unit equipped with a milking robot. In a two phase 34 day experiment with 16 Friesian-Holsteins, cows reported voluntarily to the selection unit throughout the day. Concentrates could be allocated in both the milking and selection unit. During the last 11 days, the milking robot was available for milking for 24 h a day. A set of variables and mathematical equations describing the visiting pattern and concentrates supplementation was devised.

The selection unit occupation time (about 10 h/d), together with the number of visits (about 95 visits/d), provided a good performance measure of the system capacity. It proved possible to maintain daily automatically controlled milking and concentrates supplementation. Not all concentrates (about 90% of planned) were supplemented as planned. To achieve the planned allocation of all concentrates the system must allow for revision of allocation decision during the day based on individual consumption and visiting patterns.

The use of a selection unit enables control of cow traffic and the concentrates allocation, but might slow down the traffic between the selection and milking units by a period of up to 5 min passage time. A mean shorter passage of 3.8 min/visits time between the selection and milking unit, as compared with the exit time when cows are referred to the feeding area might indicate that cows prefer the milking unit to the feeding area. With a twice daily milking regime 95% of the milking visits to the selection unit were voluntary, which means that only in 5% of all milkings, cows were brought. It is predicted that about 10% of all cows would be unable to adapt to the automatic milking system routine, and would have to be culled from the herd.

Key words: control, dairy, milking frequency, milking robot

Abbreviation key: AMS = automatic milking system, MU = milking unit, SU = selection unit
1. Introduction

Integration of the milking robot into the dairy farm should free the herdsman from the milking process (Devir et al., 1993a). To do this, a fully integrated automatic milking system (AMS) must include an automatic milking and concentrates allocation routine. In this routine each cow voluntarily visits the milking and feeding units. As a result, each cow is milked and fed according to its needs and welfare (Devir et al., 1993a,b). Cows can be managed individually in AMS (Devir, 1992). Using sensors, data-bases and data analysis models, production, feed intake and behaviour can be evaluated frequently. The AMS also offers the opportunity of using milking frequency in addition to nutrition as a factor in controlling milk production.

The feasibility and successful introduction of an automatic daily milking and feeding routine involves consideration of matters such as herd size, dairy lay-out, milking system capacity, and the pattern of cow visits to the selection and milking units as well as individual aspects such as milking frequency, feed intake and behaviour (Devir et al., 1993b). Ipema et al., (1988) reported on the feasibility of milking dairy cows in a station where a feed-dispenser was located.

A selection unit is an appliance equipped with entrance and exit gates. After a cow enters such a selection unit, she is directed (using one or more controlled gates) to a known location at the dairy, according to a management decision. A selection unit before the milking unit combined with a feed-dispenser was suggested as a place to direct cows or to the milking unit or back to the herd (Swierstra and Smits, 1989). It was found by Wierenga and Hopster (1991b) that cows could have learned the times of the day when concentrates were available and that they responded to information from the feeding station. Thus it might be expected that cows would be encouraged to visit voluntarily the selection unit with feed-dispenser (Ketelaar-De Lauwere, 1992). Feed-dispensers are located at the selection unit and the milking unit to attract cows to the milking

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### Notation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDConc</td>
<td>kg/d</td>
<td>individual pre-determined concentrates, calculated for each cow at the beginning of the experiment by the nutritional module of the “Argos” dairy management system</td>
</tr>
<tr>
<td>PrCons</td>
<td>kg/d</td>
<td>individual concentrates planned from the previous day</td>
</tr>
<tr>
<td>ConcAlloc</td>
<td>kg/d</td>
<td>daily individual concentrates supplementation which were allocated</td>
</tr>
<tr>
<td>NConc</td>
<td>kg/d</td>
<td>individual planned concentrates for the following day</td>
</tr>
<tr>
<td>SuConc</td>
<td>kg</td>
<td>concentrates allocated at the selection unit, based on interval since last allocation, concentrates planned, and concentrates already consumed, NOT during unrewarded visits and NOT during milking visits</td>
</tr>
<tr>
<td>MuConc</td>
<td>kg</td>
<td>concentrates allocated at the milking unit based on interval since last allocation, concentrates planned, and concentrates already consumed, NOT during unrewarded visits and NOT during milking visits</td>
</tr>
<tr>
<td>MilkConc</td>
<td>kg</td>
<td>pre-determined portion of concentrates allocated at the milking unit during milking</td>
</tr>
<tr>
<td>MSuVst</td>
<td></td>
<td>running mean of visits to the selection unit during the previous 10 days</td>
</tr>
<tr>
<td>Conclnt</td>
<td>h</td>
<td>time interval since last non-milking visit with concentrates which does NOT include unrewarded visit during non-milking visits</td>
</tr>
</tbody>
</table>
Validation of a daily automatic routine unit. A stand-alone milking unit combined with a feed-dispenser is already a commercial product (Bottema, 1992; Dalebout, 1993).

A directed one-way routine in a loose housing system implies the use of one-way gates and the closing-off of other passages in the cow-shed. When a one-way routine is imposed, cows may spend less time at the feeding area (Ketelaar-De Lauwere, 1992). Slow cow movement between the selection unit and the milking unit may disturb the flow of cows to the dairy. Because the teat canal is still open after milking (making cows vulnerable to mastitis) and because cows tend to visit the feeding manger after milking (Metz et al., 1987), it is recommended that the milking unit exit be located near the feeding area. This would inhibit the cow from lying down too soon after milking.

If too many cows with different milking frequencies and visiting patterns visit the selection unit throughout the day, an imbalance in individual concentrates supplementation may occur. Feed intake might then not meet pre-determined nutritional requirements. Concentrates supply should therefore be controlled according to the number of available feed dispensers, daily needs and selection unit and milking unit visits. Cows will fit their visits to the feed-dispenser into their daily rhythm. Unrewarded visits, a cow's social position within the herd and the length of daylight might affect the cow's rhythm, production and rate of feed intake (Wierenga and Hopster 1991a,b).

To justify the investment in the high-cost technical equipment the milking unit should be in maximum use. The number of cows being milked depends on factors such as: (1) the time the cow spends in the stall during milking, (2) the cows' visiting pattern to the milking robot site and (3) the attendance of a cow due for milking as soon as the previous cow has finished milking.

Because the farmer is not present each time a milking or individual concentrates supplementation decision is needed, an on-line dairy control and management system makes the decision, and implements and controls its execution (Devir, 1992). The system records on a daily basis each individual cow's planned milking frequency, the previous day's milkings, its visits to the selection unit, the duration of milking and the concentrates planned and consumed. This information is used to produce for each cow (1) pre-determined minimum and maximum milking intervals to achieve the planned milking frequency target and (2) the volume of concentrates to be allocated during milking and non-milking visits according to planned daily concentrates targets.

At the on-line level, each time a cow enters the selection unit, the dairy control and management system decides whether the cow deserves milking, or a concentrates allocation, or both. An expert system rule base used the following information to produce the decision: the cow's pre-determined milking intervals and daily concentrates target, the concentrates already consumed, the interval since the last visit (milking or non-milking), the visiting pattern, the expected milking unit occupation time, and the expected waiting time for milking at the selection unit.

The hypothesis that cows voluntarily visit a milking robot throughout the day over a longer
period has not yet been tested (Mottram, 1992). The set of individual and herd decision-making parameters shown in this paper were based on published reports, and empirical results from experimental conditions similar to the AMS routine (Rossing et al., 1985; Ipema et al., 1991; Metzer et al., 1991; Winter et al., 1992).

At IMAG-DLO, three fully-controlled daily milking and feeding routine experiments based on cows' voluntary visits were conducted between 1992 and 1994. In all experiments, the daily routine was controlled by a dairy control management system developed exclusively for the AMS dairy (Devir, 1993a). The experiment reported here is the first of the three conducted. The object of this experiment was to validate the use of the individual decision-making parameters for on-line milking and concentrates decisions and to evaluate the performance of a routine for fully-automatic milking and concentrates supply on the dairy farm. To do this, a specific regime was tested using 16 dairy cows. Because the scope of the experiment was limited to the management aspects of the AMS routine, no production aspects are discussed here.

2. Material and methods

2.1. Animals and housing

The experimental herd comprised 16 Friesian x Holstein cows, all from second lactation or higher. Average daily milk yield was 29.4 kg (±7.33) and 25.2 kg (±7.57) at the beginning and end of the experimental period respectively. Average time post-calving was 167 d (±39). Eleven cows were pregnant. Four of the non-pregnant cows came into oestrus during the experimental period.

The experimental farm cow-shed, a loose housing system, was divided into two main sections: the automatic milking section (including the concentrates feed dispensers) and the lying and feeding (only forage) area section (Fig. 1). Cows had free access from the lying to the feeding area through the passage G (Fig. 1).

The AMS section comprised two sub-sections.

(1) The selection unit. The cows attend the selection unit voluntarily (Fig. 1). When a cow is inside, the milking and individual concentrates supplementation decisions are made by the dairy control and management system. Concentrates are then allocated if needed. If the cow is sent to the feeding area, a controlled gate B leads her towards the one-way gates E and F (Fig. 1). If the cow is referred to the milking unit, the controlled gate B directs her to the milking unit entrance gate C (Fig. 1).

(2) The milking unit equipped with a feed dispenser and a milking robot. At the milking unit cows can be milked, supplemented with concentrates or both. After a cow enters the milking unit, gates C and D are closed, the feed dispenser moves forward or backward to adjust the milking unit length to the size of the cow and the concentrates allocation is triggered.
Fig. 1. The experimental farm cowshed, divided into two main sections: the automatic milking section and lying and feeding areas. Cow traffic within the automatic milking section: A, B, C, and D are under dairy control and management system control by means of gates. E and F are one-way gates. After a "go to milk" decision is made, A and C are opened, B is opened to the left position, D is closed. After "go to herd from SU" decision, A is opened, B is opened to the right position, C and D are closed. G is the free passage between feeding and lying areas. Water troughs are located in the feeding area.

If the cow deserves milking, the milking robot starts with the automatic teat cups attachment. The milking robot used is of the "Prolion" type (Bottema, 1992), in which one milking robot can serve up to four milking units. We used only one milking unit. After milking or concentrates supplementation or both, the cow leaves the milking unit through exit gate D and one way gate F (Fig. 1) to the feeding area.

The entrance to the selection unit and exit F (Fig. 1) of the automatic milking section were located in the feeding area to increase the attractiveness of visits to the selection and milking units and to prevent cows from lying down after milking (Metz et al., 1987; Winter et al., 1992).
2.2. Experimental period

The experiment lasted 34 d (from May 14 until June 16, 1992) and was divided into two time phases. The first was phase A which consisted of 23 d during which the milking unit was available for milking only from 06:00 to 12:00 h and 18:00 to 24:00 h but for concentrates allocation 24 h a day. The second was phase B which consisted of 11 d when the milking unit was available for both milking and concentrates allocation 24 h a day.

2.3. Milking and feeding management

A cow is directed to the milking unit for milking if her time since the last milking is longer than 10 h. A cow would be brought manually to the selection unit for milking if her milking interval is longer than 14 h (phase A) or 17 h (phase B). The cow with the longest interval since last milking is always brought first.

Roughage based on maize (35%) and grass (65%) silage, 6.4 MJ/kg D.M., was available ad-lib at the bunker in the feeding area. It was distributed at 09:00 h. The uneaten feed was advanced to the bunker at 16:00 h.

A pre-determined daily amount of concentrates supplementation (PDConc) was calculated for each cow at the beginning of the experiment, based on her milk production and current stage of lactation. The calculation was made using the nutritional module of the "ARGOS" management system, which is based on the "Cow model" (Hyink and Meyer, 1987). The individual pre-determined daily concentrates value, which varied from 3 to 12 kg d⁻¹ cow⁻¹, was unchanged throughout the experiment. At midnight, the next day's planned concentrates supplementation (NConc) was adjusted for each cow, based on the pre-determined daily amount of concentrates, the previous day is planned concentrates (PrConc) and the amount actually allocated (ConcAlloc) Eqn (1). An attempt was made to encourage the cows to visit the selection unit more often and to eliminate frustration by the allocation of a concentrates portion of 50 to 100 g if the cows were unrewarded with concentrates or were refused milking at the selection unit. Consequently, a concentrates portion size, of 100 g multiplied by the running mean of the number of visits made to the selection unit over the last 10 d (MSuVst), was subtracted from the next day's planned concentrates allocation for each cow, Eqn (1). Because the allocation of concentrates is dependant on the cow's visiting pattern, it was expected that comparing with planned concentrates not all concentrates would be allocated as planned or more concentrates than planned might be allocated. To eliminate large fluctuations in daily concentrates between successive days, shifting of the un-allocated or remainder of concentrates to the following day was restricted to a level of no more than 10% from the daily pre-determined planned concentrates.
Validation of a daily automatic routine

\[ N\text{Conc} = PD\text{Conc} + (Pr\text{Conc} - \text{ConcAlloc}) - (0.1 \text{ kg MSuVst}) \]

\[ \text{where} \quad \text{abs} (Pr\text{Conc} - \text{ConcAlloc}) \leq PD\text{Conc} \times 0.1 \] (1)

Once the concentrates supplementation decision was made, it could not be revised while the cow was still at the milking or selection units due to hardware limitations. The concentrates portions to be allocated during milking and non milking visits were therefore pre-calculated daily as follows.

1. Milking concentrates \((Milklcs)\). The portion available only during milking at the milking unit is given by Eqn (2). The aim was to allocate as much as possible during milking to free the selection unit for other cows. The milking unit occupation duration was estimated as 10 min (Bottema, 1992). The rate of supplementing concentrates was fixed at 100 g in 20 s. The latter allows supplementation of up to 3 kg of concentrates allocation at the milking unit for each milking visit.

\[ Milk\text{Conc} = \begin{cases} 
N\text{Conc} \times 0.9 / MF & 1 \text{ kg} \leq N\text{Conc} \times 0.9 \text{ kg} / MF \leq 3 \text{ kg} \\
1 \text{ kg} & N\text{Conc} \times 0.9 \text{ kg} / MF < 1 \text{ kg} \\
3 \text{ kg} & N\text{Conc} \times 0.9 \text{ kg} / MF > 3 \text{ kg} 
\end{cases} \] (2)

2. Selection and milking unit concentrates supplementation \((Su\text{Conc}, Mu\text{Conc})\) were the portions allocated at the selection unit and milking unit respectively during a non-milking visit or visits which were NOT of the "Go to herd", non-milking visits combined with 50 to 100 g concentrates at the selection unit, visit type (see below, Table 1, Eqn 3).

\[ Su\text{Conc} \begin{cases} 
(N\text{Conc} - (Milk\text{Conc} \times MF)) \times \text{Condet} / 24 & \text{SuConc} \geq 0.1 \text{ kg} \\
0 & \text{SuConc} \leq 0.1 \text{ kg}
\end{cases} \] where \(MuConc \geq 0.1 \text{ kg}\) (3)

\[ Mu\text{Conc} = \begin{cases} 
(N\text{Conc} - (Milk\text{Conc} \times MF)) \times \text{Condet} / 24 & \text{SuConc} \geq 0.1 \text{ kg} \\
0 & \text{SuConc} \leq 0.1 \text{ kg}
\end{cases} \] where \(MuConc \geq 0.1 \text{ kg}\)
Again, the aim was to free the selection unit as quickly as possible. Thus, if the cow deserved concentrates and the milking unit was free, she was sent to the milking unit for concentrates supplementation.

3. Visits were categorized as rewarded and unrewarded according to their assumed effect on the cow. Visits involving milking or concentrates allocation (SuConc and MuConc, Eqn 3) were considered rewarded visits. The Go to herd (Table 1) visits were considered as unrewarded. A 50 to 100 g portion for each unrewarded visit to encourage cows to visit more often and eliminate frustration ("Go to herd", Table 1, see above).

4. A portion of 1 kg was supplemented at the selection unit if a cow was referred for milking but the dairy control and management system found that she had to wait more than 5 min until the milking unit was free. This portion was subtracted from the planned milking concentrates to be supplemented during milking. A maximum waiting time for milking at the selection unit was set to provide priority for milking visits over the visits to the milking unit for concentrates only (Table 1).

Table 1 lists the possible milking and concentrates decisions which could be made by the dairy control and management system while the cow was at the selection unit. Only a small portion (50 to 100 gr) was given 1 h before and 1½ h after milking to increase the probability that a cow would attend the selection unit within the planned milking interval.

### Table 1. Milking and concentrates decision types.

<table>
<thead>
<tr>
<th>Decision type</th>
<th>Concentrates at the selection unit</th>
<th>Concentrates at the milking unit</th>
<th>Maximum waiting time for milking at the selection unit (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go to herd&lt;sup&gt;1&lt;/sup&gt;</td>
<td>50 to 100 gr</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Supplement concentrates at the selection unit&lt;sup&gt;2&lt;/sup&gt;</td>
<td>selection unit concentrates (SuConc, Eqn 3)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Supplement concentrates at the milking unit</td>
<td>50 to 100 gr</td>
<td>milking unit concentrates (MuConc, Eqn 3)</td>
<td>5</td>
</tr>
<tr>
<td>Go to milk, milking unit is free&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0</td>
<td>concentrates during milking (MilkConc, Eqn 2)</td>
<td>20</td>
</tr>
<tr>
<td>Go to milk, milking unit is busy&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1 kg while waiting for milking</td>
<td>[MilkConc-1 kg]</td>
<td>20</td>
</tr>
</tbody>
</table>

<sup>1</sup> An unrewarded visit
<sup>2</sup> If the interval since last milking is bigger than 9 h or smaller than 1.5 h then a default of 50 to 100 gr portion is allocated
<sup>3</sup> If the expected waiting time until milking is smaller than or equal 5 min
<sup>4</sup> If the expected waiting time until milking is longer than 5 min
2.4. Data acquisition and analysis

All events and parameters were continuously recorded and stored for use in the on-line decision process. A group of parameters was initiated and validated for all events. The time taken for the animal to progress through the AMS (Fig. 1) was the basic unit for analysis, defined as the time between entry to the selection unit and final return to the herd, either directly from the selection unit or after passing through the milking unit. Fig. 2 presents the sub-events during one AMS event, showing the durations of sub-events such as selection and milking unit occupation, waiting at the selection unit until exit, exit from the selection unit to the feeding area and, passage time between the selection and milking units.

One of the key assumptions was that individual cows behave differently. This implies that cows represent a source of variation in terms of analysis of variance. A second variance component included in the analysis was days. Analyses were made to investigate the consistency of cow behaviour over time. Possible dependence between successive days and cows was ignored.
Differences in visiting patterns between cows are likely to exist, and possibly depend on the current activity of other cows e.g. a visit to the selection unit or milking unit is not possible if the space is already between them occupied. In some cases, data analysis was used as a descriptive tool and only means and standard deviation were calculated. In a few cases, such as the daily concentrates consumption rate (the percentage ratio between daily planned and allocated concentrates), a more advanced analysis was carried out to estimate the variance components related to different sources of variation. Apart from the effects of explanatory variables, the analysis included the difference between the two experimental phases A and B. The statistical method used for this was the REML procedure from the statistical package Genstat 5.1 release 3.1 (Genstat 5 Committee, 1993). All results are distinguished using , or _b_ notations for experimental phases A and B respectively.

3. Results

3.1. System capacity and cow traffic

System capacity is presented in Table 2 in terms of visiting frequency and occupation times at the selection unit and milking unit. A daily average of more than 90 visits to the selection unit was recorded. About 30%_a_ of total visits to the milking unit resulted in milkings and 26%_a_ and 21%_a_ in concentrates allocation only. Out of 32 daily planned milkings, a daily average of 31.4 _a_ (±1.5) and 30.5 _b_ (±1.6) was achieved.

Table 2. System capacity as daily means of visits and occupation time at selection and milking units in experimental phases A and B.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Visits to the SU</th>
<th>Milking visits</th>
<th>MU visits for concentrates only</th>
<th>SU occupation</th>
<th>Waiting at SU until exit</th>
<th>MU occupation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>96.9</td>
<td>31.4</td>
<td>26.0</td>
<td>9.6</td>
<td>2.5</td>
<td>9.8</td>
</tr>
<tr>
<td></td>
<td>16.0</td>
<td>1.5</td>
<td>5.9</td>
<td>1.8</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>B</td>
<td>94.3</td>
<td>30.5</td>
<td>20.0</td>
<td>10.0</td>
<td>1.8</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>9.0</td>
<td>1.6</td>
<td>6.0</td>
<td>1.2</td>
<td>0.5</td>
<td>0.8</td>
</tr>
</tbody>
</table>

The selection unit and milking unit had a similar occupation rate of about 10.5 _a_ h/d, well under full system capacity. A daily waiting time for milking at the selection unit rate of 2.5 _a_ and 1.8 _a_ h/d means that the selection unit was occupied by a cow waiting to leave for the milking unit because the latter was still occupied. 29%_a_ and 25%_a_ of the daily milking unit occupation were due to
Validation of a daily automatic routine concentrates visits only. More than 70% of the occupation time during these non-milking visits was spent in activities other than eating, such as entering and leaving the milking unit, and opening and closing gates etc. Mean AMS event parameter values per cow per visit are presented in Table 3. The milking unit occupation during non-milking visits is relatively high. The sum of the waiting time at the selection unit until the exit gate opened, and the passage time between the selection and milking units yields a duration of more than 5 min/visit. This means that on average, 5 min elapsed from the time the cow was able to leave the selection unit until milking could start.

Table 3. Average durations of AMS sub-events min/cow visit, with standard errors, for the experimental phases A and B

<table>
<thead>
<tr>
<th>Phase</th>
<th>Exit from SU to the feeding area</th>
<th>Passage between SU and MU</th>
<th>Waiting at SU until exit</th>
<th>MU occupation during milking visits</th>
<th>MU occupation during non-milking visits</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Mean 6.3</td>
<td>2.8</td>
<td>2.4</td>
<td>13.2</td>
<td>9.96</td>
</tr>
<tr>
<td></td>
<td>s.e. 0.5</td>
<td>0.3</td>
<td>0.22</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>B</td>
<td>Mean 6.9</td>
<td>2.7</td>
<td>2.17</td>
<td>15.3</td>
<td>7.62</td>
</tr>
<tr>
<td></td>
<td>s.e. 0.5</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The passage time between the selection and milking units was significantly shorter than the exit time from the selection unit when cows were referred to the feeding area. The average difference was 3.8 min/visit (s.e. 0.25) (Table 3). The selection unit exit time for visits when cows were referred to the feeding area and received a concentrates portion of 50 to 100 gr was also found to be significantly shorter (1.5 [min/visit], s.e. 0.54) compared with visits involving long queuing before being sent to the milking unit. Comparing exit time when the cows were sent to the feeding area shows that the visits involving small concentrates portions of 50 to 100 gr a were shorter by 1.45 min/visit (low significance) compared with visits involving long queuing and shorter by 1.89 min/visits (high significant difference, s.e. 0.89)

![Fig. 3. Relative distribution of visits to the AMS divided according to the decision making at the selection unit. Phase A: empty bars; Phase B: full bars.](image-url)
Fig. 4. Individual non-voluntary milking visits as percentage of all milking visits. Phase A, empty bars; Phase B full bars. The figures above the full bars represent the absolute number of non-voluntary visits in phase B.

Fig. 5. Visits to the automatic milking system as percentage of total divided into 6x4 h periods. Phase A: ■ Phase B: ▲.
compared to visits involving a high amount of concentrates allocation.

Distribution of visit types throughout the experiment is presented in Fig. 3. In more than 50% of the visits, the cows were referred to the milking unit. The selection unit was used for concentrates allocation over 100 gr for less than 5% of the daily selection unit occupation time. Voluntary milking visits achieved 92.6, and 95.4% of planned milking frequency (Fig. 4). Twelve of the total 16 non-voluntary visits were made by cows 725 and 832 (Fig. 4).

To show the effect of diurnal rhythm, the daily average of visits to the AMS and the occupation rate of the selection unit was chosen. Fig. 5 shows the frequency of the daily visits to the AMS in six daily phases, of 4 h each. The relatively high peaks in phase A at 12:00 h and 20:00 h, are due to the fact that cows were brought at the end of the shift when the milking unit was available for milking. Fig. 6 presents the mean daily selection unit occupation rate calculated as a percentage of the total potential occupation time in six 4 h periods. On average the selection unit was occupied more during the night than during the day.

Fig. 6. Selection unit occupation rate shows as percentage of total potential occupation in 6x4 h time periods. Phase A: ■; Phase B: ▲.
Validation of a daily automatic routine

Experimental phase

Fig. 7. The percentage ratio between planned and consumed concentrates for experimental phases A and B, and high and low daily planned concentrates. Concentrates allocated only during milking events are shown as full bars; concentrates allocated during non-milking events (apart from small portions up to 100 gr) are shown as empty bars; small portions up to 100 gr are shown as crossed bars.

3.2. Individual concentrates supplementation and consumption

Daily concentrates consumption rate reached an average level of 97.8% and 89.7% of planned. Residual variation deviation was found to be high. The daily planned concentrates varied from 3 to 12 kg/d. No more than 6 kg/d could be allocated during milkings (milking frequency=2; maximum concentrates during milking = 3 kg, Eqn 2). In 34.4% and 9.3% of all visits involving selection unit concentrates, the amount of selection unit concentrates was less than 100 gr, which in fact can be considered as a kind of a treat for the cow. The values of concentrates consumption rate were divided into three different types: concentrates consumed during milking events, concentrates consumed during non-milking visits (except for up to 100 gr concentrates consumed in unrewarded visits) and "Go to herd" (Table 1) visits involving up to 100 gr concentrates (Fig. 7). Results are presented at two daily planned concentrates levels: less and more than 6 kg/d. In 19.6%, and 16.6% of all concentrates consumption at the milking unit, the size of the portions was smaller than 300 gr. Because concentrates portions were pre-determined only once daily according to the type of visits (Eqn. 2) it could not be adjusted during the day and some cows were supplemented more than planned.
Table 4. Average daily concentrates consumption rate: allocation as percentage of daily planned concentrates, for experimental phases A and B divided by amounts smaller and greater than 6 kg/d and identified by location and type of supplementation

<table>
<thead>
<tr>
<th>Phase</th>
<th>Daily amount of daily planned</th>
<th>Location and type of concentrates supplementation</th>
<th>Total consumption rate of planned kg/d</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>kg/d</td>
<td>SU, MU, during milking</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SU, NOT during milking</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MU, while waiting for milking</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SU, unrewarded visits</td>
<td>%</td>
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<tr>
<td>A</td>
<td>≤6</td>
<td>1.5</td>
<td>88.0</td>
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<td></td>
<td></td>
<td>17.0</td>
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<td></td>
<td>&gt;6</td>
<td>3.3</td>
<td>53.0</td>
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<td>24.0</td>
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<td></td>
<td></td>
<td></td>
<td>86.0</td>
</tr>
<tr>
<td>B</td>
<td>≤6</td>
<td>2.4</td>
<td>68.0</td>
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<td></td>
<td></td>
<td></td>
<td>14.0</td>
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<td></td>
<td>11.3</td>
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<td>9.9</td>
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<td>6.3</td>
<td>51.0</td>
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<td>2.5</td>
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<td></td>
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<td>87.0</td>
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</table>

3.3. The individual cow

The following components for concentrates consumption rate were estimated from an analysis of variances: cow $\sigma^2_c$, the interaction of cows with experimental phases $\sigma^2_{cp}$, days $\sigma^2_d$, and residual $\sigma^2_e$. The analysis of variance (REML procedure, Genstat S Committee, 1993) for applied concentrates consumption rate with fixed effects of phase and the above-mentioned four variance components (standard error in brackets gave): $\sigma^2_c = 167(79)$, $\sigma^2_{cp} = 47(29)$, $\sigma^2_d = 33(15)$ and $\sigma^2_e = 449(29)$. These figures mean that there is a variation between individual cows, but only a small variation for each cow over the days and between experimental phases. When variances were corrected for the effect of experimental phase A,B, and for cows with high and low daily planned concentrates, the main source of variation between days for the low daily planned concentrates was found to be the amount of concentrates allocated during non-milking events.

4. Discussion

4.1. System capacity and cow traffic

Waiting time at the selection unit (from the time the last concentrates portion is given until the cow is free to leave) is a meaningful variable in measuring the AMS traffic flow. The selection unit waiting time is clearly dependent on the rate of the milking unit occupation time. Milking unit occupation depends on three factors: I) the milking process, i.e. the rapidity of teat cup attachment by the milking robot, the ability to re-attach teat cups which fall off during milking, and the time needed for udder cleaning, II) the cow's behaviour during and after teat cup attachment (Ordolff, 1987) and III) physiological aspects such as milk flow and the amount of milk.
Validation of a daily automatic routine to be milked during one visit. The latter affects the relative teat position and increases teat cup attachment time (Hogewerf et al., 1992). Figs. 5 and 6 show the pattern of visits to the AMS and occupation of the selection unit. Because waiting time at the selection unit is a key factor in the evaluation of AMS traffic, the use of this figure rather than number of visits to the AMS as an indicator of system capacity throughout the day might be more appropriate.

The passage time between the selection and milking unit was found to be significantly shorter than exit time from the selection unit to the feeding area, with an average difference of 3.8 min/visit (s.e. 0.25). This might indicate that cows learned to associate gate position with what was going to happen. In the reported experiment, the milking unit was apparently preferred to the feeding area. It is also possible that the milking unit location was associated with concentrates allocation because most supplementation occurred there.

Of all visits, 6.2% and 9.3% involved too long a waiting time at the selection unit or dispatch to the feeding area instead of milking because of hardware or software failure. It is suggested that cows might feel disappointed when they wait too long at the selection unit without concentrates supplementation and are then sent back to the herd. That is why such visits should be categorized "disappointment visits". Any decisions made in the system should take account of such effects on future cow behaviour in modelling of such system.

If the milking robot is available for milking 24 h/d the addition of more selection units would increase the flexibility of the dairy control and management system. It would enable the assessment of priorities between the cows, a reduction in waiting time at the selection unit according to the herd and cows' diurnal rhythm, and use of these time gaps to allocate individual concentrates supplementation, if needed. In this way traffic flow through the AMS section would be improved. Based on the assumptions of 6-10 [min/milking] (Bottema, 1992; Van der Linde and Lubberink, 1992), and a maximum waiting time at the selection unit of 25 to 30 min, a ratio of two selection units to one milking unit is suggested.

A further way of increasing AMS capacity would to minimize the passage time and occupation time in the AMS section (see Fig.2). The latter might be dependant on the cows' behaviour pattern, barn lay-out structure and decision-making.

4.2. Individual concentrates supplementation and consumption

There was a high variance in concentrates consumption between cows. This can partially be explained by the difference in daily planned concentrates. In the group with the low daily planned concentrates, consumption was not as high as planned, Eqn (1), (Table 5). This group's consumption of concentrates was affected more by the small portions (smaller than 100 gr) than that of the group with the high daily planned concentrates (Fig. 7). The latter group's consumption was dependent on the number of visits to the selection unit and the intervals between successive
visits.

On average, concentrates supplemented during milking contributed the most to the daily concentrates consumption rate (Table 4, Fig. 7). This fact might suggest that a planning to allocate most of the concentrates at the milking unit, (90% of all planned, Eqn. 2) enables only a limited flexibility in concentrates allocation during the day and is therefore, a useful method. If concentrates are supplemented only at the milking unit, as was reported by Rossing et al., (1985), the daily planned concentrates calculation should be \([\text{milking frequency} \times \text{maximum milking unit concentrates}]\) (kg/milking). If a selection unit exists, it enables more concentrates to be supplemented. However, the amount of concentrates to be allocated outside milking time in the selection unit is dependent both on maximal waiting time at the selection unit and on the concentrates supplementation dispensing rate (such as 100 gr each 20 sec). If the amounts of concentrates allocated are too great, selection unit occupation time may increase, causing disruption to cow traffic.

Excluding two of the 16 cows (Fig. 4) the average number of voluntary milking visits exceeded 98.9% of all milking visits. The fact that cows present themselves voluntarily at the selection unit is partially dependent on daily rhythm (Fig. 5,6). There are not enough data to analyze statistically the exact causes but the data might indicate a diurnal pattern. However, it is recommended that milking and concentrates supply decisions should be made taking daily rhythm into account.

4.3. The individual cow

We used the concentrates consumption rate [\%] parameter in an analysis of variance to show how AMS data should be handled. A relatively high \(\omega_c\) indicates that cows should be treated individually, although in the present analysis they were grouped according to a population characteristic, such as the size of daily planned concentrates allocation. A relatively low \(\omega_c\) means that there is hardly any extra variation in the concentrates consumption rate from day to day that cannot be explained by the residual variation. This means that each cow is consistent in its concentrates consumption rate throughout the time period.

It might be concluded that using the above-mentioned AMS parameters based on continuous individual updating enables the characterization of individual cow behaviour, as well as the herd pattern.

4.4. More management perspectives

These results prove that maintaining an automatic routine based on cows' voluntary visits and a milking robot is possible. However, many features still need to be investigated and improved. The selection unit was not equipped with any device to force the cow to leave. Consequently, high
Validation of a daily automatic routine

rates of exit time from the selection unit and passage time between the selection and milking units (up to 70 min) were recorded. Pushing the cow out of the selection unit by mechanical means might reduce idle time values. It was also suggested that the removal of the walls between the dairy section, selection unit and milking unit (Fig. 1) might increase the cows' motivation to move between selection unit, milking unit and dairy section.

Results might suggest that using the milking unit as the only location for concentrates allocation is not preferable. However, since the milking unit was occupied only 10 h/d, it might be concluded that the use of the milking unit as a location for concentrates allocation only should be proportional to planned milkings.

Only 5% of total daily waiting time at the selection unit was due to milking unit occupation by other cows receiving concentrates only (for types of visits, see Table 1). This means a relatively small disturbance of cow traffic in the AMS section.

The average milking event duration was 15.16, and 16.65, min (composed of passage time between selection and milking units plus milking unit occupation time). Excluding two cows with a relatively high difference from the mean of 1.65 min (s.e. 0.528) yields a milking event duration of 14.7, and 16.2, min. These results and the non-voluntary milking visits results, might suggest that not all cows are suited to AMS. It would therefore be beneficial to the system, to cull from the herd the small number of cows unable to adapt sufficiently to the AMS routine.

5. Conclusions

The results confirm that automatic milking, based on voluntary visits of cows to a selection unit equipped with a feeder dispenser is feasible. Visit times, occupation time and idle time proved good measures in evaluating AMS capacity and traffic flow. On-line milking and feeding decisions should be based on individual as well as on herd parameters. In any further behavioural analysis, each cow should be treated as an individual. Selection unit occupation time is the preferred indicator for system capacity evaluation. The time a cow has to wait at the selection unit before she is sent to the milking unit causes a bottle-neck in AMS cow traffic. Any reduction of its duration would improve traffic flow.

Feed intake was not always as planned. Allocating concentrates should be done in a more flexible way rather than based on a daily update. The calculation of maximal individual concentrates supplementation should be based on milking frequency, the concentrates supplementation dispensing rate, time available for concentrates supplementation, and the number of milking unit and selection units. If concentrates are allocated in milking unit outside milking time, allocation should be proportionally to the planned number of herd milkings. Those cows which cannot adapt their behaviour to the AMS routine would have to be culled from the herd.
Any further development in AMS should consider the management aspects mentioned above no less than the milking robot itself. Since no other reference for testing AMS under full AMS circumstances is available, more empirical tests are needed to validate the AMS parameters presented in this paper.

Acknowledgment

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References


Validation of a daily automatic routine
Chapter 4

The milking robot dairy farm management: operational performance characteristics and consequences.

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Abstract

A herd of 29 dairy cows which voluntarily attended a milking robot site was milked for eight weeks. The milking robot was available for 24 h a day. Milking frequency varied between 2 and 5 times a day. The daily milking and concentrates routine was automatically controlled by a DCMS (dairy control and management system) developed at IMAG-DLO. On-line milking and concentrates allocation decisions were made as the cows voluntarily visited a selection unit before the milking robot site. The herd was automatically milked and fed almost as planned. The DCMS succeeded in adjusting cow visits to the milking unit at relatively equal intervals throughout the day. In a dairy farm with two selection units, one milking unit and unrestricted voluntary cow traffic, about 120 milkings a day can be achieved. Cow visits to the selection unit and milking unit were sufficient to allow the supplementation of high yielding cows with a large amount of concentrates. Based on the herd's visiting profile, the number of cows and individually planned milking frequency, the farmer may restrict his physical involvement in bringing cows to the milking robot.

Key words: dairy, control, management, milking frequency, milking robot

Abbreviation key: AMS = automatic milking system, DCMS = dairy control and management system, ICS = individual concentrates supplementation, MF = daily milking frequency

1. Introduction

The milking robot as a stand-alone unit is already a commercial product world-wide. However, an automatic milking system (AMS) is more than a machine for attaching teat cups. Fully integrated AMS systems are not on the market yet.

The dairy AMS farm includes a milking robot sensors, controlled gates, and self-feeders. The AMS is controlled by a dairy control and management system (DCMS),(Devir et al. 1993a). In the AMS each cow can be milked and fed according to her own planned milking frequency (MF) and planned individual concentrates supplementation (ICS). On-line tracing of the cows' body weight, dry matter intake and milk yield and composition enable individual adaptation of MF and planned ICS (Maltz and Metz 1994). Production is then likely to increase (Maltz et al., 1992). The DCMS uses dynamic updating of individual and herd behaviour performance characteristics for the on-line decision-making to regulate cow visits to the milking unit and to control ICS. AMS performance focused on three issues: the integration of the cow into the AMS system environment, system performance and capacity and the cows' production performance.
1.1. The integration of the cows into the AMS environment

A selection unit is already used in some dairies for automatic cow sorting (Carrono, 1994). Using a selection unit in the loose housing AMS farm enables control of cow milking, movement and ICS (Devir et al. 1993b). The AMS must respect all relevant physical and psychological characteristics of the animals involved (Hurnik 1994). If a cow which deserves milking, voluntarily enters the selection unit but is sent back to the herd due to either a system failure, a wrong milking or ICS decision, or too long a waiting time, this might frustrate her and negatively affect her visiting pattern.

To achieve a voluntary milking routine, cows should be attracted to the selection unit. Cows eat all their rations of concentrates as soon as they are made available (Wierenga et al., 1991b). The cows’ visiting/feeding behaviour patterns are directly related to the fixed-time concentrates-feeding routine (Livshin et al., 1994). Rewarding cows with concentrates might
help in regulating cow visits (Pierkelmann, 1992). Thus, in the AMS dairy concentrates are allocated only at a selection or milking unit (Ketelaar de-Lauwere, 1992, Devir et al., 1993b, 1994).

Cows keep to the same daily rhythm and behaviour patterns over time (Metz-Stefanowska et al., 1992). Research into the effect on animal behaviour of milking several times a day has shown that cows prefer to visit the feeding area more often than the milking parlour (Swierstra and Smits, 1989). It might be expected that cow visits to the milking unit would be distributed unequally throughout the day (Wierenga and Hopster, 1991a) since cows do not act independently of each other but more typically as a coordinated social unit (Hurnik, 1994).

It was reported by Devir et al., (1994) that using a selection unit might slow down cow traffic between the selection unit and the milking unit and the rest of the barn. The slowdown might be caused by cow behaviour and system lay-out. A mechanical device to push the cows out of the selection unit, or opportunities for eye-contact between cows in the selection unit and the milking unit, were suggested to reduce the cow exit time from the selection unit (Devir at al. 1994). However, idle time due to cow movement is to be expected.

1.2 System performance and capacity

From the individual cow point of view, the AMS's ability to implement for each individual cow a planned MF and ICS might serve as a criterion of success for the DCMS operation. From the AMS point of view, the maximal number of milkings a day when cows report voluntarily to the milking unit serves as a success criterion.

To eliminate frustration, the occurrence of social vices and the reduction of social tolerance among group members, AMS compartments should serve as many cows as possible simultaneously (Hurnik, 1994). The number of selection units depends mainly on the herd size, the number of daily planned milkings and the amount of ICS to be allocated. System capacity should be planned according to the highest capacity possible of maximum \textit{planned}_ics and MF. Because each cow might have her own MF, the system capacity should be determined not only in terms of cow numbers but in terms of number of milkings a day as well.

To increase system capacity, cows should stay at the milking unit and selection unit as briefly as possible. The availability of a cow to attend the milking unit when it is vacant, and cow motivation to attend the selection unit according to the planned MF, are one of the key factors for the success of the AMS cow traffic routine. From the system capacity point of view it is preferable that cows visit the selection unit only when necessary. If a cow deserves milking or extra ICS then she is expected to visit the selection unit. When cows do not deserve milking or ICS they are not welcome there. The time a cow spends at the milking
The operation of the milking robot dairy management

unit should consist mainly of net milking machine time. The duration of other activities, such as entering, teat cup attachment and exit, should be as short as possible.

Because ICS is supplemented only at the milking or selection units, low visiting pattern cows with a low MF and high daily planned ICS might not succeed in consuming all planned ICS. An attempt should be made to use the selection unit for ICS allocation only while cows are waiting for milking. The situation where the milking unit is available but the selection unit is occupied only because of concentrates allocation, should be avoided.

2. Objectives

A new concept and tools for the fully AMS dairy farm have been developed at IMAG-DLO (Devir et al., 1993a). A feasibility field test conducted at IMAG-DLO showed that automatic milking based on voluntary cows visit to a selection unit, controlled by a DCMS based on herd and individual on-line milking and feeding decisions is applicable (Devir et al. 1993b, 1995).

Using the results of previous AMS experiment (Devir et al., 1993b, 1995) a longer automatic milking and feeding routine experiment, based on voluntary cow visits to the selection unit, was conducted at IMAG-DLO. A herd of 29 cows was milked in an AMS dairy, equipped with a milking robot and controlled by a DCMS for 8 weeks. The aim was to milk cows with different individual MF and daily ICS when they would voluntarily visit the AMS under maximal capacity circumstances. As a result of the experiment, the integration of the cows into the AMS environment and the system performance and capacity were studied to enable improvement of the DCMS methods and tools.

This paper addresses the main components, structure and environment of the fully integrated AMS dairy and presents results from the field test. Because the focus of the paper is the AMS management perspective, no production aspects will be discussed here.

3. Material and methods

3.1 General experimental design

The herd comprised 29 cross bred Holstein-Friesians: 17 from lactation = 1 and 12 cows from lactation > 1. Cows differed in their lactation stage: 12 and 17 cows within 6-74, and 175-244 days from calving respectively, at the beginning of the experiment. The 305 days annual mean yield was of 9096 kg milk (± 1645), fat and protein content of 4.8% (±0.6) and 3.6% (±0.2) respectively.

The experiment lasted from March 3rd until May 13th 1993. The experimental period was divided into two phases A and B: 22 and 26 days respectively. The phases differed in ICS, milking management and barn structure (Figs. 1 and 2, Table 1). In the second experimental
Fig. 1. The experimental barn divided into the AMS and dairy section. The dairy section comprises lying and feeding area with two free access points (H, I) between them. The exit from the AMS section after milking was always to the feeding area (E). The entrance to the selection unit was always from the feeding area (A). Exit after non-milking visits was to the feeding or lying area (F). This chart presents the barn architecture during the first experimental phase A. The cows had a free choice where to go after the non-milking visits.

Phase, cows at the beginning of lactation were selected for high MF, 5 times a day (10 cows). The cows at the later stage of the lactation were selected for medium MF, 3 times a day (17 cows). During phase B, two sick cows were changed from high MF to medium MF.

All equations, tables and results in this paper are distinguished using a or b notations for the experimental phases A and B respectively.

Forage consisted of a mixture of 60% grass silage, 20% maize silage and 20% corn cob silage, with 1343, 1496 and 1735 Kcal/kg dry matter respectively, and was available ad-lib at the bunk. It was distributed once a day at 1200 h and shoved twice a day at 0900 and 0100 h.

3.2. Experimental barn architecture

The experimental loose housing barn was divided into two main sections: the AMS section and the lying and feeding section (Fig. 1), without walls between the dairy section, selection
The operation of the milking robot dairy management

Fig. 2. The AMS section. Entrance selection unit gates (A) were opened until a cow entered the selection unit. If a cow was sent to the milking unit: selection unit exit gate, B1 or B2, opened and controlled gate C moved to position C2 or C3 for the left or right selection unit respectively; milking unit entrance gate D1 opened; milking unit exit gate D2 was closed. If a cow was sent back to herd: selection unit exit gate, B1 or B2, opened and controlled gate C moved to position C1 or C2 for the left or right selection unit respectively. In the first experimental phase, cow left AMS section via one-way gate F. In the second experimental phase, controlled gate G could divert the cows to the lying area (G2) or to the feeding area (G1). If no cow was recognized at the one-way gate F and it was closed, controlled gate G reversed to position G3. One-way gate E eliminated cows entering the milking unit from the wrong direction. The figure presents the barn architecture during the second experimental phase.

unit and milking unit to allow the cows eye contact (Hurnik, 1994). Cows could pass freely through two passages between lying and feeding area sections (H, I, Fig. 1). The water troughs were located at the feeding section. Concentrates were supplemented only at the selection or milking units.

If the exit and entrance from the selection units are close to one another, cows which visit too often might block the system. Lying down after milking, while the teat canal is still open, is not recommended (Metz et al., 1987). Cows tend to approach the water trough immediately after milking (Metz-Stefanowska et al., 1992; Pirkelmann, 1992), so the exit from the AMS section after milking always led to the feeding area (E, Figs 1 and 2). The entrance to the selection unit was located at the feeding area (A, Figs. 1 and 2).
(F, Fig. 1). In phase B a second diversion gate (G, Fig. 2) was installed. By default the gate was on position G3, enabling the cows to choose their destination. Cows found visiting the selection unit too often (two successive visits within a 20 min interval) were diverted to the lying area (G2, Fig. 1, Table 1). To prevent cows from lying down after milking, they were diverted to the feeding area within an hour after milking (G1, Fig. 2, Table 1).

An attempt was made to keep the width and the turning angles of the passages within the AMS section as recommended (Rogerson, 1972). Aisle's width was 80-90 cm. It was reported by Devir et al. (1993b, 1995) that traffic flow within the AMS section is sometimes slowed down due to idle time. To reduce idle time, the distance between the milking and selection units was reduced as much as possible in this barn.

The milking unit was equipped with a "Prolion" milking robot (Bottema, 1992). Cows could be milked and supplemented with concentrates for almost 22 hours a day. The milking unit was not available for milking daily from 0700 to 0800 h due to thorough cleaning and maintenance. Twice a day at 1600 h and 0000 h a 20 min short cleaning procedure was carried out. Low intensity artificial light was used during the night.

3.3. Cow traffic control

Cow movement through the AMS section is described as a series of time events, from T[1] to T[9] during one AMS visit and are presented in detail in Fig. 3. After a cow enters the selection unit (T[1]) the milking and ICS decisions are made by the DCMS (Devir et al., 1993). If the cow deserves supplementation at T[2] concentrates are allocated until T[3]. If the cow is sent to the herd, and the area between the selection unit and the one-way gate (B-C-F, Figs. 1 and 2) is free, the exit selection unit gate (B1,2 Fig. 2) opens and 10 sec later a mechanical "pusher" is activated to encourage the cow to leave the selection unit. A Cow which deserves milking, is directed to the milking unit (D, Fig. 2). If the latter is occupied the cows is supplemented with a supercandy concentrates portion until milking unit is free (Table 1, Eqn. 6).

If the milking unit is available, the selection unit exit gate opens (B2, Fig. 2; T[4], Fig 3). To decrease high idle time between the selection and the milking units the first portion of milking ICS (100 gr) is triggered by the cow's detection within the area of the milking unit entrance gate (D1, Fig. 2; between T[4] and T[5], Fig. 3). The rest of milking ICS is supplemented during milking. At the end of the milking (T[8]), the milking unit exit gate opens, and a mechanical "pusher" behind the cow is activated. If the milking ICS portion allocation is incomplete, it is stopped. At T[9] the milking unit is available again for the next cow.
Table 1. The DCMS on-line decision making for experimental phases A and B. Decisions are divided into milking, non-milking and the destinations the cows were referred to. The decision numbers in Fig 4 are the same as in this table.

### Experimental phase A

<table>
<thead>
<tr>
<th>decision no.</th>
<th>deserve milking?</th>
<th>where to go</th>
<th>why</th>
<th>ICS&lt;sub&gt;1A&lt;/sub&gt;</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>yes</td>
<td>go to the milking unit</td>
<td>time since last milking &gt;= 6 h</td>
<td>candy, milking&lt;sub&gt;ics&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>2a, 3a</td>
<td>no</td>
<td>back to herd, free choice</td>
<td>time since last milking &lt; 6 h</td>
<td>su&lt;sub&gt;ics&lt;/sub&gt;</td>
<td>see Eq. 2</td>
</tr>
<tr>
<td>4a</td>
<td>yes</td>
<td>back to herd, free choice</td>
<td>1. waiting too long for milking</td>
<td>candy</td>
<td>ICS = 0 if ics_consumed &gt; (planned&lt;sub&gt;ics&lt;/sub&gt; - (milking&lt;sub&gt;ics&lt;/sub&gt;*MF)</td>
</tr>
</tbody>
</table>

Maximum su<sub>ics</sub> = 1.1 kg/visit
Maximum milking<sub>ics</sub> = 3.5 kg/visit

### Experimental phase B

<table>
<thead>
<tr>
<th>No.</th>
<th>deserve milking?</th>
<th>where to go?</th>
<th>why</th>
<th>ICS&lt;sub&gt;1A&lt;/sub&gt;</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1b</td>
<td>yes</td>
<td>milking unit</td>
<td>within milking&lt;sub&gt;interval&lt;/sub&gt;</td>
<td>candy, milking&lt;sub&gt;ics&lt;/sub&gt;</td>
<td>wait&lt;sub&gt;at_su&lt;/sub&gt; &lt; 5 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>supercandy, milking&lt;sub&gt;ics&lt;/sub&gt; (see Eq. 6)</td>
<td>wait&lt;sub&gt;at_su&lt;/sub&gt; &gt; 5 min and wait&lt;sub&gt;at_su&lt;/sub&gt; &lt;= 25 min</td>
</tr>
<tr>
<td>2b, 3b</td>
<td>no</td>
<td>back to herd, free choice</td>
<td>time since last milking &lt; milking&lt;sub&gt;interval&lt;/sub&gt; and time since last milking &gt;1 h</td>
<td>su&lt;sub&gt;ics&lt;/sub&gt; (see eq. 5)</td>
<td></td>
</tr>
<tr>
<td>4b</td>
<td>yes</td>
<td>back to herd, free choice</td>
<td>maintenance and cleaning time OR system failure</td>
<td>supercandy or candy</td>
<td>If wait&lt;sub&gt;at_su&lt;/sub&gt; &gt; 5 and wait&lt;sub&gt;at_su&lt;/sub&gt; &lt;= 25 min or other</td>
</tr>
<tr>
<td>5b</td>
<td>no</td>
<td>feeding area</td>
<td>time since last milking &lt; 1 h</td>
<td>candy</td>
<td>teat canal is still open</td>
</tr>
<tr>
<td>6b</td>
<td>no</td>
<td>lying area</td>
<td>too often visit selection unit</td>
<td>0</td>
<td>20 min interval between successive visits</td>
</tr>
</tbody>
</table>

Maximum su<sub>ics</sub> while non milk<sub>vst</sub> = 1.1 kg/visit
Maximum milk<sub>ics</sub> = 2.1 kg/visit
Minimum milk<sub>ics</sub> = 0.1 kg/visit
A mean of 5 non-milking visits a day and a mean \textit{su\_idle\_time} duration of 2.7 min/visit in AMS free routine was reported by Devir et al., (1995). Under conditions of 100 gr each 20 sec ICS dispensing rate and a maximum of 3.5 ICS kg/visit, two selection units were installed for a herd of 30 cows, with a maximum total planned 100 milkings/day when one milking unit is used.

Field test results and milking robot firms indicate a teat cup attachment duration of 30 to 180 sec (Hogewerf et al., 1992, Frost et al., 1993, Rossing et al., 1994), net milking machine time of 7.4 to 5.1 min/cow for MF 2 and 6 respectively (Ipema et al., 1991) and about 14 min/milking\_visit (Devir et al., 1994). For decision-making, an average \textit{mu\_occup} and \textit{mu\_idle\_time} was estimated at 10 min/cow and 3 min/cow respectively (Devir et al., 1994). 25 min were therefore adopted as the maximum duration the cows could be forced to wait for milking at selection unit (\textit{wait\_at\_su}).

3.4. Daily and on-line feeding and milking management

In phase A all cows were sent to the milking unit if their milking intervals (\textit{milking\_interval}) were between 6 and 10 h from the last milking. In phase B the high MF cows had a planned \textit{milking\_interval} with a minimum of 4 h and a maximum of 7 h, while the medium MF cows had a planned \textit{milking\_interval} with a minimum of 6 and a maximum of 9 h since last milking. Cows which did not report voluntarily to the selection unit within their planned

![Fig. 3. The time events during one milking or non-milking AMS event. T[1] and T[5] are the entrance times to the selection and the milking units respectively. T[4] and T[9] are the exit times from the selection and milking units respectively.](image-url)
The operation of the milking robot dairy management took place by the farmer.

Based on the nutritional module of the "ARGOS" management system (Kroeze, 1990), the daily recommended ICS, \((\text{argos} \_\text{ics}, \text{kg/day})\) portion was calculated for each cow at the beginning of the experiment.

In both phases A and B, a daily calculation of the next days' \(\text{planned} \_\text{ics}\) was made, based on the cow's consumption the previous day and the next days' \(\text{argos} \_\text{ics}\) (Eqn. 1). A value of 10% was set as the threshold to eliminate sharp fluctuations between successive days (Devis et al., 1995). In phase A cows were supplemented with three pre-calculated portions: \(\text{milking} \_\text{ics}\) and \(\text{su} \_\text{ics}\) and \(\text{candy}\) (Table 1, Eqn. 4). The allocation of \(\text{ics} \_\text{su}\) was proportional to the interval from the last non-milking visit and the amount of ICS planned and already consumed since the previous midnight (\(\text{ics} \_\text{consumed}\); Eqn. 2).

\[
\text{su} \_\text{ics} = \begin{cases} 
\frac{\text{ics} \_\text{int} \times (\text{planned} \_\text{ics} - (\text{MF} \times \text{milking} \_\text{ics})))}{24} & \text{ics} \_\text{consumed} > (\text{planned} \_\text{ics} - (\text{MF} \times \text{milking} \_\text{ics}))) \\
0 & \text{ics} \_\text{consumed} \leq (\text{planned} \_\text{ics} - (\text{MF} \times \text{milking} \_\text{ics}))) 
\end{cases}
\]  

(2)

Throughout the experiment a \(\text{milking} \_\text{ics}\) value for each cow was calculated each day based on \(\text{planned} \_\text{ics}\) and \(\text{visiting} \_\text{pattern}\) (Eqn. 4).

In phase B an attempt was made to adapt the ICS plan to the individual cow based on the cow's behaviour and daily planned ICS and MF. Cows were classified according to their visiting pattern. Cows which adapt their visiting pattern to their MF were classified as \(\text{visiting} \_\text{pattern}=1\). These cows were milked voluntarily during the last 3 days according to their planned MF. All other cows were classified as \(\text{visiting} \_\text{pattern}=0\) (Eqn. 3).

The day was logically divided into time windows of 4.5 h and 8 h each for high MF and medium MF cows respectively. To encourage low visiting pattern cows to increase \(\text{su} \_\text{vst}\), and to discourage high visiting cows from visiting when it was not necessary, the cows with a high visiting pattern (\(\text{visiting} \_\text{pattern}=1\)) were supplemented with \(\text{su} \_\text{ics}\) (Eqn. 4) only in the first non-milking visit within the time window, while low visiting pattern cows (\(\text{visiting} \_\text{pattern}=0\)) got a \(\text{candy}\) portion each visit.

\[
\text{visiting} \_\text{pattern} = \begin{cases} 
\sum_{j=1}^{3} \text{milking} \_\text{visit}[j] & \text{if } \sum_{j=1}^{3} \text{milking} \_\text{visit}[j] \geq \text{MF} \\
1 & \text{if } \sum_{j=1}^{3} \text{milking} \_\text{visit}[j] < \text{MF} \\
0 & \text{other} 
\end{cases}
\]  

(3)
The operation of the milking robot dairy management

\[
\text{milking}_{ics} = \begin{cases} 
0.1kg & \text{planned}_{ics} \leq MF \times 0.1 \\
3.5_{a} \times 2.0_{b} & \text{milking}_{ics} > 3.5_{a} \times 2.0_{b} \\
\text{and} & \\
\mu_{ics} \text{ dispensing} > 18\text{sec} & \\
\text{milking}_{ics} \text{ dispensing} < 18\text{sec} & \text{other}
\end{cases}
\]

\[
\text{su}_{ics} = \begin{cases} 
0.1kg & \text{visiting pattern} = 0 \\
\text{plannd}_{ics} - \text{(milking}_{ics} \times MF) \times MF^{-1} & \text{visiting pattern} = 1 \\
\text{and} & \\
\text{milking}_{ics} > 3.5 kg & \text{other}
\end{cases}
\]

Concentrates were allocated at the selection unit in a mean constant dispensing rate of 100 gr each 23 sec (s.e. 0.601) throughout the experiment. To keep the cow busy with concentrates while being milked, an individual milking_{ics} dispensing rate, \mu_{ics} \text{ dispensing}, based on the last 3 days running mean of daily \mu_{occup} (\text{Ravg}_{mu_occup}) and milking_{visit} (\text{Ravg}_{milking_visit}), was calculated daily (Eqn. 5).

\[
\text{mu}_{ics} \text{ dispense} = \frac{(\text{Ravg}_{mu_occup} \times \text{Ravg}_{milking_visit}^{-1})}{(\text{milking}_{ics}/100^{-1})}
\]

If a cow had to wait for milking at the selection unit for more than 5 min, she was supplemented with a supercandy of 1/3 of the planned milking_{ics}, which was subtracted from the milking_{ics} (Eqn. 6). These portions were allocated to the cows according to a DCMS decision (Table 1).

In phase A a simple control program was used, while in phase B an expert-system, based on individual cow performance, was used. The on-line milking and ICS decisions taken at the selection unit are described in Table 1. In this table the milking and non-milking decisions are categorized by the direction in which the cows were referred ("where to go", Table 1). The ICS allocated in each of the cases is recorded, and a short explanation is provided separately.
\[
\text{milking}_\text{ics} = \begin{cases} 
\text{milking}_\text{ics} - \text{supercandy} & \text{su_wait} > 5 \text{ min} \\
\text{supercandy} - \frac{\text{milking}_\text{ics}}{3} & \text{su_wait} \leq 5 \text{ min} \\
\text{milking}_\text{ics} & \text{other}
\end{cases}
\] (6)

for both experimental phases A and B.

3.5 Data acquisition and statistical analysis

On-line data was acquired at the selection and milking units. Each time event within the AMS section (Fig. 3) was recorded. Each day a running mean of the previous 3 days of su_visit, voluntarily milking_visit, mu_occup and mu_idle_time, was calculated and used to adjust DCMS decision parameters.

The cows' distribution at the barn was observed. The barn was logically divided into 5 sub-sections: the entrance to AMS, the exit from AMS, the AMS section, the lying and feeding areas. The barn was observed each half hour. Then the number of cows in each of the above-mentioned sections was recorded into the data base.

Analyses were carried out for summarized data (totals for days or for cows) as well as for individual data. Apart from the effects of explanatory variables, the analysis included the difference between the two experimental phases A and B.

An individual analysis was carried out to learn the characteristics of individual cow behaviour under AMS circumstances. A model was built to evaluate separately for each cow the different effects on interval between two successive visits, (inter-visits) to the selection unit. The analysis covers all inter-visit times observed. The following factors were chosen as explanatory variables:

1. Experimental phase A and B.
2. Cow lactation, classified as Lactation = 1 and Lactation > 1.
3. The amount of ICS consumed during the last visit. This was categorized into classes of < 0.1, 0.1-0.5, 0.5-2 and >2 kg/visit.
4. Performed MF, which was smoothed using a cubic smoothing spline technique (Hastie and Tibshirani, 1990). The MF was categorized into 3 classes: <2.5, 2.5-3.5 and >3.5 milking/day.
5. The type of previous visits, classified as presented in Table 1 and Fig. 4.
6. Because the system changed between the phases, interactions of the effects of ICS-consumption, lactation number and visit type have been incorporated into the model (interactions between [2,3 and 5])
7. Cows, a random effect with means 0 and constant variance.
8. The day, a random effect with means 0 and constant variance.

The classes of the explanatory variables 1,2,3,4 and 5 act as levels of the factors. In phase A the cows hardly differ in milking frequency, whereas in phase B cows have been differentiated in this respect. The interaction of phase and milking frequency has therefore not been included in the model.

The mean inter-visit time is related to explanatory factors on the logarithmic scale. This ensures non-negative means, while the model is multiplicative. The error involves differences between cows and between days. The residual variance was assumed to be related to the mean according to a power relationship. The results of the analysis are expressed as tests of factorial effects and as estimates of effects (estimates for each level of a factor compared with level 1 of the factor) with standard errors. For testing factorial effects (concerning multiple comparisons e.g. the effect of visit types) Wald test statistics were used (Genstat Committee, 1993). The Wald test statistics divided by its degree of freedom is identical to the F-statistics with their degree of freedom for the numerator, and infinite degree of freedom for the dominator. Using Wald test in a hierarchical way, each effect is corrected for previous effects tested, but ignores effects that have been added later. The tests provide a means of establishing roughly the relative importance of the factorial effect as an explanation of inter-visit time. The analysis may be indicated as a logarithmic analysis of variance. The algorithm used was Iterative Reweighed REML (Engel and Keen, 1994; Keen, 1994). For all statistical analysis the statistical package Genstat 5.1 release 3.1 was used (Genstat 5 Committee, 1993), in particular procedure IREML for the individual analysis.

Table 2: Mean ratio daily concentrates consumption to planned. Results are divided by level of daily planned ICS, Low < 6kg/day, High >6 kg/day and place of allocations for phases A and B.

<table>
<thead>
<tr>
<th>visit type</th>
<th>milking visits</th>
<th>milking visits</th>
<th>non-milking visits</th>
<th>daily visits</th>
</tr>
</thead>
<tbody>
<tr>
<td>location</td>
<td>selection unit</td>
<td>milking unit</td>
<td>selection unit</td>
<td>milking unit a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>std</th>
<th>mean</th>
<th>std</th>
<th>mean</th>
<th>std</th>
<th>mean</th>
<th>std</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ics_planned &lt; 6 kg/day</td>
<td>13.3</td>
<td>11.6</td>
<td>60.3</td>
<td>28.5</td>
<td>23.1</td>
<td>35.2</td>
<td>96.6</td>
<td>44.3</td>
</tr>
<tr>
<td>ics_planned &gt;= 6 kg/day</td>
<td>5.9</td>
<td>6.2</td>
<td>64.8</td>
<td>19.8</td>
<td>22.0</td>
<td>15.7</td>
<td>92.7</td>
<td>20.9</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ics_planned &lt; 6 kg/day</td>
<td>25.0</td>
<td>15.8</td>
<td>30.0</td>
<td>17.6</td>
<td>36.8</td>
<td>52.9</td>
<td>91.8</td>
<td>62.2</td>
</tr>
<tr>
<td>ics_planned &gt;= 6 kg/day</td>
<td>17.4</td>
<td>8.6</td>
<td>27.5</td>
<td>17.0</td>
<td>17.7</td>
<td>16.2</td>
<td>60.9</td>
<td>23.7</td>
</tr>
</tbody>
</table>
RESULTS

4. General results

The medium MF and high MF mean daily milk yield per cow were 18.95 ±9.7 and 30.74 ±14.91 kg/day per cow respectively. Daily mean performed MF was 2.83 ±0.16 milking/day in phase A and 2.87 ±0.26 and 3.93 ±0.25 in phase B for planned MF of 3 and 5 times respectively. Mean milk yields [kg/visit] divided by experimental phases are presented in Table 6.

Daily concentrates consumption did not exceed planned consumption. Analyzing the daily ratio ICS consumed to planned, \( \text{ics\%} \), yields a difference between the cows with \text{planned\_ics} higher and lower than 6 kg/day (Table 2). The cows with the high daily \text{planned\_ics} had a significantly lower ratio of ICS allocated to planned in phase B comparing to phase A. The analysis suggests that the main source of the low daily ICS allocation is the ICS allocated during milking visits. Most of the daily \text{planned\_ics} was planned for allocation during milking visits (Eqn. 4). The high MF cows, which also had the highest daily \text{planned\_ics} were not milked as planned. That is why there were fewer opportunities to allocate ICS to the cows, and as a consequence, not all the daily \text{planned\_ics} was allocated.

4.1 Visits to selection unit

The AMS daily mean number and duration of milking unit and selection unit visits are presented in Table 3. The milking unit was occupied on a daily basis longer in phase A than in phase B while the selection units were occupied on a daily basis longer in phase B than in phase A (\text{su\_occup}, \text{mu\_occup}, p < 0.01, Table 3).

<table>
<thead>
<tr>
<th>phase</th>
<th>su_occup (2 selection unit)</th>
<th>mu_occup</th>
<th>su_visit</th>
<th>milking_visit</th>
<th>su_ics intervals visits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>h / day</td>
<td>h / day</td>
<td>visits / day</td>
<td>visits / day</td>
<td>su_visit /cow</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>std</td>
<td>mean</td>
<td>std</td>
<td>mean</td>
</tr>
<tr>
<td>A</td>
<td>26.81</td>
<td>3.93</td>
<td>14.06</td>
<td>0.58</td>
<td>557.3</td>
</tr>
<tr>
<td>B</td>
<td>36.67</td>
<td>2.68</td>
<td>13.45</td>
<td>0.84</td>
<td>264.0</td>
</tr>
<tr>
<td>s.e. of difference</td>
<td>1.187</td>
<td>0.249</td>
<td>55.78</td>
<td>5.31</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Table 3: AMS daily performance means and s.e. of differences between experimental phases A and B. \text{su\_ics} interval visits is the mean daily number of \text{su\_visit} excluding milking visits, visits within 1 hour after milking and visits within 1 h since last visit. All differences between experimental phases are significant (\( p < 0.01 \)).
The operation of the milking robot dairy management

Visit types

Fig. 4. Relative distribution of visit at selection unit types, divided by experimental phase A and B. For explanation, see Table 1.

The "no milking - free choice" (decisions 2\textsuperscript{ab} and 3\textsuperscript{ab} Table 1) decisions comprise three subtypes: I) short interval visits, when all visits occurred within an interval of less than an hour since the last \textit{su_visit}. 73% of all short interval visits were heifers, with a mean difference between heifers and cows of 145 visit/cow (P<0.01), II) unrewarded milking visits \textit{i.e.} visits in which a cow deserved milking according to her planned \textit{milking_interval} but was referred back to the herd. Communication failures within the system caused unjustified rejection of 5.9\textsubscript{a}, and 11.35\textsubscript{a} of all visits to the selection unit, and III) other visit types (Table 1).

Fig. 4 presents the visit type distribution divided into phases A and B. Deviations between individual cows were large and exceeded a difference of more than 14 visits/day per cow. The \textit{su_visit} was found to be affected significantly more by the cows' parity than by the planned MF.

The voluntary milking visits are presented in Figs. 5a and 5b. On average, non-voluntary milking visits exceeded 8.6\textsubscript{a}, and 11.5\textsubscript{a}, of all \textit{milking_visit}. Eliminating all non-voluntary milking visits which were caused by unjustified rejection (decisions 4\textsuperscript{ab} Table 1), the non-voluntary milking visits were 7.1\textsubscript{a} and 8.8\textsubscript{a}. 
Fig. 5a,b. Non-voluntary milking visits for the different experimental phases and planned MF groups. MF = 3, 5a; MF = 5, 5b. Phase A - (empty bars), Phase B - (full bars).
The results of the individual analysis, expressed as tests of factorial effects, and as relative effects between classes of each effect, are presented in Table 7. Wald test statistics, all highly significant, indicate that after the interaction of the experimental phase, the type of last visit is the factor which most affects the inter-visit interval (WSS values, Table 7). The effects of the parity, ICS consumed and type of visit were all found significant. The individual analysis shows that heifers were more active than cows in the way they visited the selection unit more often and, especially in short visit types. Activity in phase A was higher than in phase B. The number of milkings a day did not affect cow visits if they were milked more than 2.5 times a day. Referring cows to the lying and feeding areas caused cows to visit the selection unit again later compared with free choice and short interval visits. The relatively shortest intervals were found after unrewarded milking visits. The amount of ICS allocated during the last visit affected the next visit only at levels above 0.5 kg/visit.

4.2. AMS time budgeting

Due to a communication delay between the time the cows entered the selection unit, and the time the gate controller received the DCMS decision, an average delay occurred in the second experimental phase of almost 3 min/visit (Table 4). The mean duration the cows spent at the selection unit, \( su_{occup} \), is presented in Table 4 separately for milking and non-milking visits. The cows spent more time at the selection unit (after "go to herd" decision) in the second experimental phase because of the communication decision delay.

<table>
<thead>
<tr>
<th>su_occup go to herd</th>
<th>su_occup go to milking unit</th>
<th>decision delay</th>
<th>wait_at_su go to herd</th>
<th>mu_idle_time</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>std</td>
<td>mean</td>
<td>std</td>
<td>mean</td>
</tr>
<tr>
<td>A</td>
<td>1.54</td>
<td>0.50</td>
<td>11.20</td>
<td>1.11</td>
</tr>
<tr>
<td>B</td>
<td>6.90</td>
<td>1.33</td>
<td>12.21</td>
<td>0.89</td>
</tr>
</tbody>
</table>
The *wait_at_su* duration is dependent partly on the system and partly on the cow. In non-milking visits, a system delay in opening the selection unit exit gate could occur if the space between the selection unit and milking unit was occupied by cows (C and D, Fig. 2, Table 4). After the exit selection unit gate is opened, *wait_at_su* duration is dependent on the speed at which cow leaves the selection unit. The duration of *wait_at_su* in milking visits is a result of the occupation status of both the selection unit and milking unit when the cows entered the selection unit, and the duration of milking time. Table 5 presents *wait_at_su* before milking for different types of AMS occupation status. In 80%, and 72% of the milking visits (significant difference, \( p < 0.01 \)) cows had to wait at the selection unit until the milking unit was free (Table 5). Despite the fact that more cows had to wait for milking at the selection unit in phase B compared to A (daily mean of difference 13.9 cows, \( p < 0.01 \)) no significant difference in waiting time per visit was found. However, this fact did result in a higher daily *su_occu* in phase B compared to A (Tables 2 and 4). Due to the absence of the exact times when the cows left the selection unit on non-milking visits we cannot characterize the cause of the *wait_at_su* during these visits in order to discriminate between effect of the cows and the effect of the system. However, the *mu_idle_time* values which are presented in Table 4 do exhibit only the cow effect.

One milking unit event is the time from when the cow is free to leave the selection unit until she is out of the milking unit after milking (T⁴ to T⁹, Fig. 3). A milking unit event comprises the following successive components (Fig. 3): *mu_idle_time*, enter_mu, att_time, *milking_time* and exit_mu (Table 6). All the milking unit event component durations depend both on the cow's behaviour and the system performance (Devir et al., 1995). Table 6 details the mean duration of one milking unit event for each experimental phase A and B. Standard deviation is presented separately for between cows and between days.

Table 5: *wait_at_su* occurrences and durations while cows were waiting for milking.

<table>
<thead>
<tr>
<th></th>
<th>phase A</th>
<th>phase B</th>
<th>phase A</th>
<th>phase B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>events / visit</td>
<td>events / visit</td>
<td>min / visit</td>
<td>min / visit</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td>std</td>
<td>mean</td>
<td>std</td>
</tr>
<tr>
<td>milking unit is free, selection unit is free</td>
<td>22.95</td>
<td>6.68</td>
<td>17.92</td>
<td>3.91</td>
</tr>
<tr>
<td>selection unit is free, milking unit is busy</td>
<td>30.92</td>
<td>6.72</td>
<td>38.15</td>
<td>6.69</td>
</tr>
<tr>
<td>selection unit is busy, milking unit is busy</td>
<td>29.50</td>
<td>1.50</td>
<td>36.15</td>
<td>8.92</td>
</tr>
</tbody>
</table>
Table 6: Mean values per visit and the visits’ components. Because some of the milking unit components of the visit duration are affected by cow, day or both, std are given with respect to days and cows.

<table>
<thead>
<tr>
<th></th>
<th>mu_idit</th>
<th>enter_mu</th>
<th>att_time</th>
<th>milking_time</th>
<th>exit_mu_time</th>
<th>AMS event</th>
<th>milk yield MMF</th>
<th>milk yield HMF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min / visit</td>
<td>min / visit</td>
<td>min / visit</td>
<td>min / visit</td>
<td>min / visit</td>
<td>min / visit</td>
<td>kg/ milking</td>
<td>kg/ milking</td>
</tr>
<tr>
<td>A mean</td>
<td>1.07a</td>
<td>0.39</td>
<td>1.93</td>
<td>6.39a</td>
<td>1.53</td>
<td>11.40c</td>
<td>8.84c</td>
<td>14.57c</td>
</tr>
<tr>
<td></td>
<td>0.73</td>
<td>0.08</td>
<td>0.60</td>
<td>1.48</td>
<td>0.35</td>
<td>1.79</td>
<td>2.50</td>
<td>2.83</td>
</tr>
<tr>
<td></td>
<td>0.21</td>
<td>0.05</td>
<td>0.25</td>
<td>0.31</td>
<td>0.26</td>
<td>0.47</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B mean</td>
<td>1.31b</td>
<td>0.41</td>
<td>1.88</td>
<td>5.34b</td>
<td>-1.36</td>
<td>10.13d</td>
<td>6.60d</td>
<td>8.20d</td>
</tr>
<tr>
<td></td>
<td>0.82</td>
<td>0.05</td>
<td>0.55</td>
<td>0.92</td>
<td>0.27</td>
<td>1.32</td>
<td>2.52</td>
<td>3.84</td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>0.06</td>
<td>0.27</td>
<td>0.37</td>
<td>0.16</td>
<td>0.47</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

a, b Means within columns with different superscripts differ (P ≤ 0.05)

A, B Means within columns with different superscripts differ (P ≤ 0.01)

5. DISCUSSION

5.1 The integration of the cows into the AMS

Results indicate that with respect to the su_visit and milking_visit cows adapt to the AMS system. Heifers adapt better than cows. Cow visits to the selection unit are affected most by what happened to them during previous visits. Cows which deserved milking and were unjustifiably rejected mostly came back within a short time. A similar effect of the unrewarded visit on the inter-visit time to a selection unit with a SF was reported by Ketelaar-de Lauwere and Benders (1994).
The operation of the milking robot dairy management

Fig. 6. Log number distribution of cows, based on manual observation each 1/2 an hour. The results are divided throughout the 5 barn sections and 6 time phases, 4 h each.

The herd's daily visits were divided equally over the day. Fig. 6 presents the log number distribution of cows occupying the various barn areas, divided into six daily equal time phases (4 h each). Throughout the experiment cows were at the AMS section entrance area 95% of the 24 h. Cows were observed at the feeding area almost all day long. The low activity in the morning both in the feeding area and at the selection units entrance was due to morning cleaning and maintenance of the milking unit. In the second time window, from 04:00 to 08:00, fewer cows were observed in the feeding and the AMS entrance areas compared to the other time windows (P<0.01). No significant difference in cow distribution was found between experimental phases. The number of cows throughout the day was significantly higher at the lying area compared to other areas. Figs. 7a and 7b, present su_visit and the relative distribution of mu_occup during the day. Despite the fact that fewer cows were observed at the feeding area and the AMS entrance area in the second time window, analysis supports the fact that no difference exists between time windows for su_visit and relative mu_occup.

It might be concluded that despite the fact that the herd was expected to develop a diurnal rhythm in the barn areas (feeding and lying), the DCMS succeeded in regulating visits to the AMS section. Occupation times at the selection and milking units were relatively equal over
Fig. 7a. Mean daily visit at SU divided by 6 time phases, 4 h each. Empty bar, phase A; Full bars, phase B.

Fig. 7b. The relative MU occupation in each of the daily time windows of 4 h each. Empty bars, phase A; full bars, phase B.
the day, especially in phase B (Fig. 7a). When occupation times are equal over the day, it is easier to achieve a higher system capacity.

There are no observations on whether the cows referred to the lying area within one hour after milking did or did not lie down within this period of time. However, comparing visits to the selection unit in phases A and B, it might be concluded that sending cows back to the herd or to the lying area, sometimes with no ICS, discouraged cows from visiting the selection unit again within a short interval. The decrease in the number of short interval visits between phases was found to be the main cause of fewer \textit{su_visits} in phase B.

Observations on the cows’ interaction with the selection unit pusher showed that some cows learned how to cope with the "pusher" device. They bent themselves sideways to avoid interference and to gain some more time at the selection unit, especially when they were referred to the herd without ICS.

The crowding of cows at the AMS exit section might disturb cows which are leaving the section. Results indicated that, on average, in 95% of the 24 h no more than 2 cows were in the AMS exit area.

5.2 System capacity

In phase A more visits to the selection unit were observed (mainly short interval visit types) than in phase B (Figs. 4 and 7a, Table 3) but the daily \textit{su_occ_un} in phase B was longer (Table 3). The explanation for this is the increase in daily milkings (table 3). This increase forced more cows to wait at the selection unit for milking until the milking unit was free (Table 5). Also, a delay in decision-making due to communication failures, especially in phase B, made those cows which had to be sent back to the herd immediately wait on average 3 extra min before they could leave the selection unit.

More milkings a day were performed in phase B than in phase A (Table 3) as a consequence of the planned \textit{milking_interval} (Table 3), but the milking unit was occupied less (Fig. 7b). The decrease in \textit{mu_occ_un} is mainly due to the shorter \textit{milking_time} of the high MF cows (MF increase means less milk each milking).

Our results show that excluding 2 h a day for cleaning and maintenance of the milking unit, (table 6), an AMS with 2 selection units and one milking unit might serve about 120 milkings a day. Reducing each of the AMS event components (\textit{mu_enter}, \textit{milking_time} and \textit{exit_mu}) would result in a theoretically higher milking unit capacity.

To achieve the planned MF cows have to report to the selection unit voluntarily at intervals which allow them to be milked as planned. A fully voluntary routine, in which all cows report voluntarily to the selection unit is not likely to be achieved. Also Rossing et al., (1987) did not achieve 100% of voluntary milking visits when cows were milked manually in a milking
Table 7: Factorial effects (on log scale) for the interval visit to the selection unit, presented for each level of the explanatory factor compared with level 1 of the factor and s.e. of differences. In brackets for each explanatory factor, Wald test statistics (WSS) and the respective degree of freedom (d.f.). The indexes attached to the visit types correspond with Fig. 4 and Table 1.

<table>
<thead>
<tr>
<th>Explanatory factor and levels</th>
<th>Relative effects</th>
<th>s.e. of differences</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experimental phase (WSS = 323.3, d.f. = 1)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>phase A</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>phase B</td>
<td>0.2784</td>
<td>0.0697</td>
</tr>
<tr>
<td>phase A</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lactation (WSS = 14.6, d.f. = 1)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lactation = 1</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>Lactation &gt; 1</td>
<td>0.3517</td>
<td>0.1039</td>
</tr>
<tr>
<td><strong>Performed milking frequency (WSS = 140.4, d.f. = 2)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MF &lt; 2.5</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>2.5 &lt; MF &lt;= 3.5</td>
<td>-0.3034</td>
<td>0.0390</td>
</tr>
<tr>
<td>MF &gt; 3.5</td>
<td>-0.3372</td>
<td>0.0450</td>
</tr>
<tr>
<td><strong>Last AMS event concentrates consumed including phase interaction (WSS = 83.7, d.f. = 3, include interaction with the phase factor)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICS &lt;= 0.01 kg</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>0.01 &lt; ICS &lt;= 0.5</td>
<td>-0.0122</td>
<td>0.0483</td>
</tr>
<tr>
<td>0.5 &lt; ICS &lt;= 2.0</td>
<td>0.1011</td>
<td>0.0533</td>
</tr>
<tr>
<td>ICS &gt; 2.0</td>
<td>0.2397</td>
<td>0.0651</td>
</tr>
<tr>
<td>ICS &lt;= 0.01 kg</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>0.01 &lt; ICS &lt;= 0.5</td>
<td>-0.0122</td>
<td>0.0483</td>
</tr>
<tr>
<td>0.5 &lt; ICS &lt;= 2.0</td>
<td>0.1011</td>
<td>0.0533</td>
</tr>
<tr>
<td>ICS &gt; 2.0</td>
<td>0.2397</td>
<td>0.0651</td>
</tr>
<tr>
<td><strong>Visit type without phase interaction (WSS = 1986.1, d.f. = 6)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>milking (1)</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>feeding area (5)</td>
<td>-0.2884</td>
<td>0.0477</td>
</tr>
<tr>
<td>lying area (6)</td>
<td>-0.3694</td>
<td>0.0587</td>
</tr>
<tr>
<td>free choice (2)</td>
<td>-0.9369</td>
<td>0.0487</td>
</tr>
<tr>
<td>short interval (3)</td>
<td>-0.9341</td>
<td>0.0508</td>
</tr>
<tr>
<td>unrewarded milking (4)</td>
<td>-1.1708</td>
<td>0.0770</td>
</tr>
</tbody>
</table>
The operation of the milking robot dairy management
robot site available during 22 h a day with a minimum milking interval of 4 to 3.5 h. Various reasons such as disease (cow 820, Fig. 5b) and heifers new to the herd (cow 6, Fig. 5b) might prevent cows from reporting to the selection unit.

Ipema et al., (1987) found that one of the reasons for a low rate of visits was a large number of animals suffering from claw disorders.

The farmer should not spend extra time on bringing cows to the milking unit. It is reasonable to assume that the average AMS farmer will visit his herd at least 3 to 5 times a day. Bringing cows in numbers less than the full capacity of the available selection unit thus involves no waiting time for the herdsman. Given equal distribution of daily su_visit, and two selection units, an estimate can be made of the expected MF. Fig. 8 presents an accumulating frequency of all interval between successive visits to the selection unit. Based on our results, for an AMS with two selection units and one milking unit, the figure helps to evaluate expected MF versus the number of cows expected to attend the milking unit voluntarily. The farmer decides which way he prefers to use the AMS: either milking more cows at a lower MF or milking fewer cows at a higher MF or any combination of the two. He can also restrict his physical

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**Fig. 8.** Cumulative frequency of visits at SU intervals. Squares, phase A; Triangles, phase B. The 98% and 92% notation present percentage of cows which are expected not to come voluntarily for milking if planned milking frequency is 3 and 4 times a day respectively.
involvement in the procedure of bringing cows. For example: for 100 milkings/day, a planned MF of 3 times a day (interval of 8 h, 98% of the cow visits) (Fig. 8) is possible. On average, the farmer may expect no more than 2 cows a day not to be milked voluntarily. If a farmer milks 120 milking/day, and visits the barn on average 4 times a day (which means bringing up to 8 cows a day to the selection unit, 2 cows each time, 92% voluntary milking visit) he should expect a MF of about 4 times a day (Fig. 8).

The planned MF of 3 and 5 times a day for medium MF and high MF respectively was not fully reached. The low mean daily MF achieved might be explained partly by the fact that sometimes, cows were rejected at the selection unit though they deserved milking. Based on our results, (Fig. 8), it might be that a milking interval of 4 to 6 h would result in more milkings a day for the high MF with the same rate of non-voluntary milking.

In phase B, the plan was to supplement cows, milked as planned for three successive days, (visiting_pattern=1, Eqn. 3) with a su_ics (Eqn. 4). Out of a total of 6865 visits, 109 cases of su_ics visits were found for a group of 11 low MF cows only. The condition for visiting_pattern=1 was too demanding to be fulfilled. In fact, all cows were supplemented with ICS at the selection unit as a candy or a supercandy (Eqns. 4 and 6, Table 3). Because the MF achieved was lower than expected for the high MF group, and because milking_ics evaluated daily based on the planned MF, the daily planned_ics was smaller in at least 20% of all high MF cows which were also the HICS group (see Eqn. 4). Maximum milking_ics was reduced from 3.5 kg/visit in phase A to 2.0 kg/visit in phase B. The reduction decision was made after observation of the cows at the milking unit. This raised doubts as to whether the cows did consume all the allocated ICS during milking. The reduced milking_ics combined with the inflexible daily pre-determination of the milking_ics contributed to the lower ics%, especially for high MF cows (which also had high planned_ics) in phase B.

On average, the duration of a single AMS milking event comprises mu_occup and su_occup (including mean waiting time at the selection unit for milking) of about 16 min, (Tables 5 and 6) allowing supplementing up to 4 kg/visit of ICS at a dispensing rate of 100 gr / 20 sec at the selection unit and the milking unit. It is expected that in the AMS farm cows at peak lactation, which deserve the highest daily planned_ics, will be milked at least 3 times a day. ICS should therefore not be allocated only during milking visits. The su_ics interval values, (Table 3), present a herd mean of number of visits excluding milking visits, visits within 1 hour after milking and visits thereafter at an interval longer than 1 h. These results indicate that cows would be available at the selection unit on average 3 to 4 extra visits in addition to the milking visits, thus allowing cows to be allocated with more ICS which had not been allocated during milking visits.
6. Conclusions

Automatic control of AMS milking, ICS and cow traffic performs a management role in the dairy using a milking robot and a DCMS.

The dairy cows adapted well to the AMS environment. However, AMS performance depends on the cows as well as on the system. Cows are not frustrated by rejection at the selection unit; on the contrary, they are encouraged to make a return visits to the AMS.

Our results suggest that in an AMS loose housing system, when cows are free to choose between milking, eating forage and lying down, the number of visits to the selection unit, which cows attend before the milking unit, is sufficient to achieve a daily MF of 4 times a day. The duration of one AMS event is assumed to be between 6 to 8 min, depending on the cow’s MF and milk yield.

Selection units and on-line DCMS are essential tools in controlling cow traffic, especially in reducing frequent visits to the milking unit, which would overload the AMS. Any waiting time at the selection unit before milking which is longer than the average milking duration, results in a reduced system capacity. The ratio of two selection units to one milking unit is sufficient to allow a relatively short waiting time before milking on the one hand and to keep cow traffic moving efficiently on the other.

Cows visit the selection unit sufficiently often to allow high ICS rations to be allocated in addition to the amount allocated during milking visits.

There will always be a small number of cows which the farmer will have to bring to the milking unit. Using his herd visiting profile, the farmer will identify his preferred management strategy, a combination of daily MF, the total number of milkings a day and the extent of his physical labour in bringing cows to the selection unit.

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Chapter 5

The management of group and individual high milking frequency and concentrates allocation in the milking robot dairy

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Abstract

Following on from earlier experiments, fully-automatic control of the milking and concentrates supplementation routine was applied to a herd of 24 cows for 7 months. The cows visited voluntarily an automatic milking system consisting of two selection units and one milking stall equipped with a milking robot. Concentrates were allocated only at the automatic milking system.

Two management concepts were tested: I) A fixed milking frequency of three times a day throughout the experiment and weekly concentrates evaluation according to the usual Dutch standard. II) Variable milking frequency of six times a day after calving, and reducing to three times a day during the experiment. The milking frequency and individual concentrates supplementation were evaluated daily by an expert-system. The management aim of the experiment was to milk and feed both groups as planned, by rewarding the cows with milking or concentrates allocation or both. This occurred only once in each of 6 time windows (4 h periods throughout the day).

Results indicate that almost all cows visited the selection unit at least once each time window. Cows to be milked 3, 4, 5 and 6 times daily were milked 106.9% (±18.6), 90.5% (±15.1), 93.9% (±17.3) and 79.9% (±15.0) respectively of the planned frequency. Cows adapted to the AMS routine within 10 days after calving and voluntarily attended the selection unit for milking in 97% of all milkings. Cows with a high daily concentrates supply, (more than 10 kg/d), were not always supplemented as planned, due to the communication limitations of the dairy control and management system prototype. However, there was enough time to allocate a high amount of concentrates (up to 18 kg/day) without slowing down the cow traffic.

It is concluded that given efficient control of cow traffic with the AMS, with cows attending the milking robot voluntarily in a one-way traffic barn, high milking frequency cows can be milked and fed concentrates individually as a practical management procedure in the dairy.

Key words: control, dairy, management, milking frequency, milking robot.

Abbreviation key: AMS = automatic milking system, DCMS = dairy control and management system, ICS = individual concentrates supplementation, MU = milking unit, SU = selection unit.

1. Introduction

The milking robot is more than a tool to relieve the farmer of the substantial work associated with the milking process. Integrating the milking robot into the loose housing dairy farm allows each cow to be milked and fed automatically according to her production and behavioural performance. Short-term experiments showed that automatic control of the milking and the concentrates allocation in the milking robot dairy farm can be used as a management routine
Group and Individual high milking frequency

(Devir et al., 1995a, b). However, there are no reports either from research institutes or from the milking robot companies describing fully-automatic control of the automatic milking system (AMS) management routine throughout full lactation, with high milking frequency and voluntary visits of the cows to the milking robot site.

Assigning cows to nutritional groups using individual production performance criteria proved a successful management approach in the dairy (Spahr et al., 1993). In the AMS dairy, the control of milking frequency and the individual concentrates supplementation (ICS) are used as tools to implement an individual milking and feeding strategy (Devir et al., 1993a). This way, each cow can be milked and fed according to her performance and body condition (Maltz et al., 1992). The implementation of the individual strategy should be adapted to the available AMS capacity and herd size (Devir et al., 1995c). Moreover, an appropriate lay-out and cow traffic control are also needed to ensure that the planned concentrates and milking strategy can be fully realized.

Control of the AMS dairy milking and feeding routine is possible using a dairy control and management system (DCMS) which controls the concentrates supplementation and the milking frequency on a daily and on-line basis (Devir et al., 1993a). The DCMS evaluates the cows' production and visiting pattern on a daily basis. Tracing the cows' individual daily milk yield and composition, feed intake and body weight since calving enables better evaluation of the cows' production capacity (Maltz and Metz, 1994). Increasing milk production using milking frequency as a husbandry management tool has already been reported by Bar-Peled (1992), Hillerton (1992), Ipema (1991), Knight, (1995b), Knight et al., (1995a) and Remond et al., (1992). In the AMS dairy it can be done at an individual level. In the case of high milking frequency, adjustments may be needed in order to respond to body weight changes and food intake (Maltz and Metz, 1994). Control of the ICS should respond to the production level and be adjusted frequently on an individual basis.

At the on-line level, the DCMS controls the cow visits to the AMS and ICS in a way that ensures the full implementation of the daily planned milking and feeding strategy. The implementation of the planned milking frequency and ICS depends on the cows' ability to attend the milking and the ICS locations on time.

Using a selection unit (SU) before the milking unit (MU) proved a good approach to enable efficient AMS traffic control (Devir et al., 1993b). The following guidelines were followed to ensure optimal cow traffic: I) the time cows spend at the MU and SU, and the passage between, them should be as short as possible II) cows should attend the SU on a voluntary basis but not too frequently III) milkings and concentrates allocation must be a consistent and simple procedure so the cows can adapt to it quickly and easily. It was reported by Devir et al., (1995b) that from the cow traffic point of view the cows adapt well to the AMS environment. Reports of Livshin et al., (1995) and Ketelaar de-Lauwere and Benders (1994) confirm that cow visits to a concentrates self-feeder site can be regulated. Programming the concentrates allocation in such a way that it
Group and individual high milking frequency corresponds with the milking frequency is possible using a time window system, in which the day is divided into equal time windows. Rewarding the cows either with concentrates or with milking in such a way to ensure they will visit the SU at least once each time window will enable implementation of each desired milking frequency. For example: six equally time windows, of 4 h each, will enable up to six milkings a day.

A new concept and tools for the fully AMS dairy farm have been developed at IMAG-DLO, the Netherlands (Devir et al., 1993a,b). Following on from previous AMS experiments, a long term automatic milking and feeding control routine experiment was conducted based on voluntary visits of cows to the AMS.

The aim of this paper is first to describe the main components, structure and environment of the fully-integrated AMS dairy. Then, AMS performance under two different milking frequency regimes will be presented. Finally, the paper discusses the effects of cow behaviour, system performance, and the interactions between the two, on the system's ability to implement an individual management strategy.

2. Material and methods

2.1. General experimental design

The experiment lasted 7 months, from August 1993 until April 1994. The herd comprised 24 Holstein-Friesian cows calved between August and November 1993. The herd consisted of two experimental groups. The fixed milking frequency group (FMF), of 2 primiparous and 8 multiparous, was milked three times a day throughout the experiment and fed with concentrates according to the Dutch standard (see Kroeze and Oving, (1987)). The variable milking frequency group (VMF) (4 primiparous and 10 multiparous) was milked six times a day after calving. In the course of the experiment, the milking frequency was reduced to three times a day based on production and behaviourial performance (Maltz and Metz, 1994). The concentrates supply and milking frequency were evaluated daily (see below) (Grinspan et al., 1995).

It is essential to test the AMS performance under full capacity conditions. At the beginning of the experiment, the experimental herd comprised 24 non-fresh cows in different stages of lactation. Each time a cow in the herd calved, she was inserted into the experimental herd and assigned randomly to the FMF or to the VMF group. As a result, one of the 24 non-fresh cows was removed from the herd.

The cowshed, a loose housing system, was divided into two main sections: 1) AMS section comprising two SU and one MU (Fig. 1). According to the DCMS ICS and milking decisions, cows are diverted either to the MU (B-D and later E, Fig. 1), or to the feeding area (B-C, Fig. 1, table 1) (Devir et al., 1993a,b). The MU, equipped with a "Prolion" milking robot (Bottema, 1992), was
Group and Individual high milking frequency

Fig. 1. The experimental cow-shed divided into the AMS and the barn sections. The SU entrance gates A are opened if the SU is available for a new cow to enter in. After the cow enters the SU, if a milking decision is made, selection gate B is positioned in B3 or B2 for the lower and the upper SU respectively and the cow attends the MU entrance D1. After milking, exit MU gate D2 is opened and the cow leaves the MU to the feeding area via one-way gate E. Then D2 once is closed and D1 is opened, the MU is available for a new cow. If the cow deserves no milking, selection gate B is positioned to B2 and B1 for the lower and upper SU exits respectively. The cow goes to the feeding area via one-way gate C.

available 24 h a day. At 0730 h each day a long cleaning procedure prevented cow access. At 16:00 and 00:00 a 20 min cleaning procedure took place. To maintain normal dairy conditions of cow traffic during the experiment, if the milking robot did not succeed in attaching the teat cups within seven attempts or within two minutes, the teat cups were attached manually. If the cows deserved ICS, these were allocated via a self-feeder only at the SU or the MU (Devir et al., 1993b). A mechanical pusher is installed in the SU and the MU to hasten the cow on her way out.
Table 1. The DCMS on-line decision making. The decisions are divided into milking and non-milking and the destination the cows were referred to. A visit is considered as a rewarded one if it involves a milking at the MU or an allocation of ICS bigger than 100 gr at SU (in case the cow deserves no milking). First visit within time window is planned as a rewarded one. For milking intervals see appendix D. For ICS calculation, refer to Eq. 1, 2 and 3 Appendix E.

<table>
<thead>
<tr>
<th>decision No.</th>
<th>rewarded visit?</th>
<th>Milk?</th>
<th>where to go</th>
<th>why</th>
<th>ICS</th>
<th>comments</th>
</tr>
</thead>
</table>
| 1           | yes             | yes   | MU          | time since last milking > minimum milking interval | candy at SU and milk_jcs at MU (equation 1) | 1. MU is free  
2. highest priority for milking |
|             |                 |       |             | time since last milking > minimum milking interval | supercandy at SU (equation 2) milk_jcs at MU (equation 1) | 1. expected waiting time at SU until milking > 5 and < 25 min  
2. MU is busy or lower priority for milking |
| 2a          | yes             | yes   | feeding area | cleaning or maintenance time or system failure | su_jcs at SU (equation 3) | the cow is NOT expected to come again for milking within this time window |
| 2b          | yes             | no    | feeding area | 1. milking frequency < 6  
2. not all planned daily ICS can be allocated during milking visit | candy at SU | first visit within this time window, the cow deserves no milking during this time window |
| 3a          | no              | yes   | feeding area | expected waiting at SU time until milking > 25 min and MU is busy or low priority for milking | candy at SU | the cow gets the highest milking priority for the next SU visit |
| 3b          | no              | yes   | feeding area | cow is already waiting for milking more than 25 min | supercandy at SU (equation 2) milk_jcs at MU (equation 1) | MU cleaning or maintenance time has started while the cow is waiting at the SU or cow at the MU is delayed more than expected or system failure |
| 4           | no              | yes   | feeding area | MU planned routine cleaning time | su_jcs = 100 gr (a candy) at SU | NOT a first visit within this time window |
| 5           | no              | yes   | feeding area | unexpected MU maintenance or system failure | su_jcs = 100 gr (a candy) at SU | the cow is expected to come again for milking within this time window |
| 6           | no              | no    | feeding area | time since last milking < minimum milking interval | candy at SU | 1. first visits within time window, the cow is expected to come again for milking within this time window  
2. first visit within non-milking time window and no need to supplement more ICS |
II) Lying and feeding section. The lying area had 24 cubicles. One water trough was located in the lying area. An individual forage and water allocating system (Ipema and Metz, 1992) was located in the feeding area (Fig. 1). Cow traffic was restricted to one-way. To reach the lying area, the cows had to pass through a one-way gate (F, Fig. 1). The entrance to the AMS was from the lying area. To reach the feeding area, the cows had to pass through the SU (A, Fig. 1). For more details, refer to Devir et al., (1995d).

2.2. Feeding and milking regime

Forage was available all day long ad-lib. Each half hour an automatic mixing wagon filled the empty individual forage mangers, if any. The forage comprised 60% grass silage, 25% corn silage and 15% sugar-beet pulp. Forage composition is detailed in Appendix B.

The FMF cows were allocated ICS in the first days after calving as detailed in appendix A. During the rest of the experiment their daily ICS was adjusted using the nutritional module of the "ARGOS" dairy management software (Kroeze and Oving, 1987). The VMF daily planned ICS was calculated according to an expert-system exclusively developed for the AMS dairy (Devir et al., 1994; Grinspan et al., 1994; Maltz and Metz, 1994). The expert system is an adjusted individualised approach version of the Fuzzy-logic expert system for dairy cow transfer between feeding groups, developed at the ARO, Israel. This expert system uses as an input cows' parity, days from calving, and performance since the day of calving (Appendix C). Performance data since calving comprises daily BW, milk yield, ICS (planned and consumed) and milking frequency (planned and performed). The experimental daily planned ICS during the first days since calving was calculated as described in appendix A.

For both groups, if the cow was not allocated all the planned ICS (for the previous day), the unallocated amount was added to the next day's daily planned ICS. The addition of this unallocated ICS amount to the next day's ICS was limited to 50% of the previous day's planned ICS. The next day's planned ICS and milking frequency are assigned only if the DCMS confirms that

### Table 1. Cont.

<table>
<thead>
<tr>
<th></th>
<th>no</th>
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<th>1. time since last milking &lt; 1 h</th>
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<td>no</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- 1. time since last milking < 1 h
- 2. two successive 20 min interval visits
- 3. the former visit within the same time window
the cow will visit the SU in a visiting pattern which ensures implementation of the planned milking frequency.

It is possible that although no reduction in milking frequency is recommended by the DCMS, milking frequency is reduced because of production performance. This could occur if the number of "fetched" milking visits (Appendix D) during the previous 3 days exceeded 3, or 5, for a planned milking frequency of (2,3,4) or (5,6) respectively.

2.3. Operational control of milking, concentrates allocation and traffic control

The milking and ICS decision types, divided into milking and non-milking visits to the AMS are detailed in Table 1. The aim was to milk the cows and allocate them with concentrates in a consistent sequence throughout the lactation. The day is logically divided into six time windows, four h each, starting at midnight. A cow can have only one rewarded visit in each time window. A visit is considered as rewarded if: I) it involves milking and an allocation of concentrates at the MU and at the SU (\textit{milk\_ics} and \textit{candy} or \textit{supercandy}, Table 1, equation 1 and 2, Appendix E) or II) an allocation of concentrates at the SU (\textit{su\_ics}, equation 3, Appendix E) at the first visit in the time window if the cow does not or will not deserve milking in this time window. The aim was that a cow would be rewarded by milking or concentrates (if she did not deserve milking in this time window) on the first visit in each of the six time windows (decisions 1,2 Table 1). The following visits within the same time window result in no concentrates supplementation at the SU and immediate despatch to the feeding area (C, Fig,1; decision 7, Table 1).

If the cows' daily milking frequency is six, than she will be sent for milking at each first visit within the time window if the time since her last milking is longer than 3.5 h (decision 1, Table 1). If her milking frequency is less than 6, she will be allocated a 100 gr portion (a candy, Appendix E) at each first visit within a non-milking time window (Decision 6, Table 1). If on her first visit within a time window, a cow is expected later during the same time window, (according to her visiting pattern), she will be supplemented with a candy (Decision 6, Table 1, Appendix E).

If the cow deserves milking, then she is sent immediately from the SU to the MU. If the latter is occupied the cow waits at the SU until it is free. If two cows come to the SU within 5 min of each other, they are assessed and priority is established. A cow which deserves milking always has priority over a cow which does not deserve milking. If a cow deserves a milking rewarded visit, but she cannot be rewarded for any reason (waiting too long at SU, cleaning or maintenance time or system failure) she will get the highest priority for milking over other cows on her next visit to the SU. If two cows have the same priority, the cow with the shortest interval since her last milking will be selected for milking first in order to encourage her to keep to this visiting pattern. If a cow is expected to wait for milking at the SU, a time period of 5 to 25 min, she deserved a bigger concentrates portion called the \textit{supercandy} (decision 1, Table 1; equation 2, Appendix E).
The intention was to allocate ICS as much as possible while the cow was waiting at the SU because sometimes there was not enough time to allocate all the planned concentrates \((\text{milk}_{-}\text{ics}, \text{equation } 1, \text{Appendix E})\) during milking.

Cows are allocated a maximum of 4 kg ICS in the MU and the SU at each milking visit, which means a theoretical maximum of 24 kg/day. If all the planned daily ICS cannot be allocated during milking-only visits for high yielding cows with milking frequency smaller than 6, a \(\text{su}_{-}\text{ics}\) portion is allocated in a non-milking time window (Decision no. 2, Table 1, Eq. 3, Appendix E).

In an attempt to re-create practical AMS dairy conditions, cows which do not attend the SU voluntarily within their planned milking frequency are brought by the herdsman at only four fixed times a day, 00:00, 00:06, 12:00 and 18:00. Priority is also given to cows whose interval since last milking is longer than their "fetching" interval (Appendix D, milking intervals).

To keep the cow busy during milking, a flexible ICS dispensing rate is calculated individually before each milking according to expected milking time and \(\text{milk}_{-}\text{ics}\) (Eq 3, Appendix E). An ICS dispensing rate of 100 gr each 20 sec was set as a maximum value for the MU self feeder and as the fixed value for the SU self feeders (Appendix E).

2.4. The AMS management system

The AMS management system comprises a DCMS, a data-base containing analyzed and external data, on-line data acquisition facilities, robot milking, self-feeders and gate controllers and a capacity for reports (Devir et al., 1993a,b). The DCMS controls the dairy routine at daily and on-line levels. At the daily level milking frequency and daily ICS recommendations for the next day are made. The milking and ICS on-line decisions made at the SU are implemented via the milking robot, self-feeders and gate controllers. The DCMS interface allows the farmer to call up a graphic presentation of production and behavioural information so he can revise each one daily, and make on-line DCMS decisions (Devir et al., 1995d, 1993a,b). Decision-making sensitivity, and thresholds such as ICS limitations, waiting times, and milking intervals and frequency can be adjusted externally by the farmer. Analyzed and external data are compiled daily into individual production and behavioural patterns. The data which are acquired and analyzed on-line and off-line are detailed in Appendix C, Data acquisition and utilizations.

The DCMS continuously cycles waiting for events to occur or for pre-defined times in order to initiate operation. When a cow enters the SU an on-line milking and concentrates decision is made (Table 1). Then all relevant time events are compiled to assess the AMS occupation state (see Appendix C). This information is used whenever a milking and ICS decision is needed for the next cow entering the SU. Because of the hardware limitations of the DCMS prototype (Devir et al., 1995d), a revised decision for milking or ICS could be made for the previous cow only when a new cow enters the SU.
At pre-determined times the system lists the cows which need to be brought to the MU by the farmer. At midnight, each day a daily update procedure is triggered in which the daily system capacity and the cows' performance and behavioural performance are evaluated. Then the milking frequency and ICS for the next day are determined.

2.5. Data acquisition and analysis

Appendix C details the type of data which was acquired on-line throughout the day at the various locations in the dairy. The cows' performance data comprised BW, milk yield and food intake. The cows' visits and times spent at the SU, MU and forage feeders were recorded. The durations of ICS allocation, milking robot attachment, milking, entrance to and exit from the SU and MU were recorded continuously. If data was missing it was not completed or reconstructed in any way. The data was stored at the DCMS data-base and was used for visiting pattern characterization and decision making. Forage and concentrates dry matter content were measured once a week. Milk composition was checked twice a week for fat, protein, lactose and SCC content at a commercial laboratory. Clinical health and reproduction events were inserted manually when needed at the DCMS data-base. To ensure accurate data acquisition, a calibration of all the measurement facilities was conducted each month.

During the first weeks of the experiment, doubts were raised as to whether all the allocated concentrates were fully consumed. For this reason, on one day each week during the milking visit only, if a cow did not consume all the allocated ICS at the MU or the SU, the unconsumed concentrates were collected and measured.

Analyses were carried out for summarized data (totals for days and cows) as well as for individual cow data. Apart from the effects of the explanatory variables, the analysis included random effect between cows and between days. This way, the error involves differences between cows and between days. The results of the analysis are expressed as tests of factorial effects, and means with standard errors, using the generalized linear mixed models (Engel and Keen, 1994; Hastie and Tibishirani, 1990) and the REML procedure of the statistical package Genstat 5™ (Genstat Committee, 1993).

According to the expected effects, some variables were pre-categorized by levels to be used as factorial effects for data summary and analysis.

a. The visiting pattern analysis was conducted according to the assumed effect the former visit might have on a subsequent visit of the cow. The visits were categorized into three main types: milking rewarded, ICS rewarded, and unrewarded (1, 2 and 3 to 7 respectively, Table 1). We assumed that from the cows' point of view, if she comes within an interval of time since her last milking which allows her to be milked, any rejection is unjustified. However, too many visits to the SU overloaded the AMS and were not welcome. Un-rewarded visits were
therefore, divided into un-justified rejections, which were caused mainly by system failures and maintenance procedures (decision no. 3, 4 and 5 Table 1) and justified rejections where the cow visits the SU at intervals shorter than her planned milking frequency interval (decision no. 6 and 7 Table 1, Appendix D).

b. To demonstrate the daily diurnal visiting pattern of the cows, an individual daily visiting index on a scale of 0 to 6 was set up e.g. visiting at least once within each of the daily time windows results in an index of 6, while visiting at least once within only 3 time windows, results in a daily index of 3.

c. It was expected that the main effect on the cows' production and visiting pattern would be the milking frequency. The applied milking frequency was categorized according to the actual milking frequency, using four levels: low, for twice a day milking; medium, for three times a day, high for four milkings a day and very high, for 5 and more than 5 milkings a day. Because in only 2% out of the total daily events recorded cows were milked twice a day, mainly due to cow lameness, mastitis or system failures, the low level was omitted from some parts of the analysis.

d. When the DCMS decision making was built, it was assumed that the cows would need no more than 10 days to adapt to the system. The stage of lactation effect is therefore categorized into two levels: the first 10 days of the lactation (the adaptation period) and the rest of the lactation.

e. Experimental groups FMF and VMF.

f. The planned ICS which were categorized according to the data distribution into levels of 0-1, 1-2, 2-4, 4-14 and 14-18 kg/d.

For testing factorial effects (concerning multiple comparisons), Wald's test statistics were used (Genstat Committee, p.564, (1993)). When the Wald test is used in a hierarchical way, each effect is corrected for previous effects tested, but effects that have been added later are ignored.

3. Results

3.1. SU visiting pattern

During the 7 months of the experiment about 56,000 visits to the SU were observed. 26% of all visits were milking rewarded. In .76% and 3.8% of all milking visits, in FMF and VMF groups respectively, cows had to be brought by the herdsman because of too long an interval since the last milking ("fetching" interval, Appendix D). The mean number of daily milkings, visits to the SU, and the visiting index throughout the lactation are presented in Fig. 2. The mean visiting index was 5.39 ±0.9 without significant differences between experimental groups. On 3555, 2004 and 930 days (out of a total 6489 daily records) the cows visited the SU at least once in 6, 5 and less
Group and individual high milking frequency

Figure 2. Daily number of visits to the SU (•), mean visiting index per cow per day (+) and daily number of milkings (*) throughout the experimental period.

On average, the 24 cows visited the two SU and the MU 258.1 ±42.8 and 85.4 ±8.4 visits/d respectively. The maximum daily SU and MU visits were 347 and 106 respectively. In the course of time, a reduction of daily visits to the MU resulted in a higher daily visit rate to the SU (Fig. 3a,b). Mean daily SU visits per cow were 8.3, 10.6, 11.9 and 10.8 visits/d for applied milking frequency of 2 (low), 3 (medium), 4 (high) and higher than 4 (very high) respectively. The high milking frequency cows visited the system more often than the low and medium milking frequency cows.

The herd developed a diurnal pattern. Fig. 4 represents the daily mean values of SU and MU occupation times and the total number of daily visits to the SU and the MU divided into 6 time windows. Fig. 3a,b,c, and d represent the mean daily MU and SU occupation duration and the total daily MU and SU visits, divided into 6 time windows throughout the experimental period. The cows visited the SU less during the first half of the day compared to the second half (P<.05). The lowest MU and SU occupation times were observed between 04:00 and 07:59 (P<.001). The daily one h MU cleaning procedure occurred during this period. Despite the diurnal pattern of the number of visits to the SU, the MU was occupied almost equally throughout the day, between 2.14 to 2.54 h/time window in the second and first time window respectively (P<.01).

The system failure had a significant effect, locally by time, on the applied milking frequency and ICS allocation. Fig. 5 represents the mean daily applied milking frequency, the visiting index
Fig. 3a. Total daily visits to the MU divided into 6 time windows 4 h each throughout the experimental period. Each strap from bottom to top represents time window from the first in the day until the last one respectively.

Fig. 3b. Total daily visits to the SU divided into 6 time windows of 4 h each throughout the experimental period. Each strap from bottom to top represents time window from the first in the day until the last one respectively.

Fig. 3c. Daily MU occupation divided into 6 time windows of 4 h each, throughout the experimental period. Each strap from bottom to top represents time window from the first in the day until the last one respectively.

Fig. 3d. Mean daily SU occupation time divided into 6 time windows of 4 h each throughout the experimental period. Each strap from bottom to top represents time window from the first in the day until the last one respectively.
Figure 4. Mean daily SU and MU occupation time and mean number of daily SU and MU visits, divided into 6 time windows of 4 h each.

and the concentrates consumption throughout the experiment. The vertical lines in Fig. 2 and Fig. 5 indicate the dates when the system did not function as planned due to calibration procedure or system failure.

3.2. Control of cow traffic, visits to the SU and MU

3.5% of the total un-justified un-rewarded visits to the SU were due to the MU cleaning time (decision no. 4, Table 1), 1.94% were due to system failure (milking robot and communication, decision no. 5, Table 1) and 1.82% involved too long a waiting time (decisions 3a, and 3b, Table 1). Fig. 6 presents the relative distribution of rewarded and justified unrewarded visits divided into four levels of performed daily milking frequency, low, medium, high and very high. The higher the milking frequency, the higher is the percentage of milking visits and short interval visits (interval since last milking < 1 h) of all visits. The lower the milking frequency, the greater is the proportion of the ICS rewarded visits and unrewarded visits (excluding the short interval ones).
Almost 98% of all visits to the SU had an interval shorter than 6 h. Many of the visits to the SU were short-interval ones. Of all visits to the SU 30% and 57% were visits succeeded by interval lengths of 45 min and 2 h, respectively.

All cows to be milked two and three times a day were milked as planned. Fig. 7 shows the milking frequency performed for each of the planned milking frequency levels separated from the first 10 days, which was the adaptation period (see Appendix D, milking intervals). The applied milking frequency in the first 10 days compared to the rest of lactation was significantly lower (P<.05).

3.3. Control of the ICS

Not all concentrates were allocated as planned. Most of the concentrates (82% ±40%) were allocated during milking visits. Fig. 8 presents the allocated concentrates divided into four types of concentrates supplementation: during the milking visit - milk_ics (equation 1, Appendix E), while waiting at the SU for milking - Supercandy (equation 2 Appendix E), during non milking time windows (su_ics, Decision no. 2, Table 1, Eq. 3 Appendix E) and a 100 gr portion during non-rewarded visits (candy, Decision No. 3,4,5,6 Table 1). Because planned ICS proved to have the most
Fig. 6. Relative distribution of milking rewarded, unrewarded, time window concentrates and unrewarded short interval visits of all the visits to the SU divided into four levels of applied milking frequency. The decision types coincide with decision numbers 1, 6, 3 and 7 from Table 1 respectively.

Fig. 7. The mean applied milking frequency as percentage of the total planned for different milking frequency levels, divided into adaptation period (first 10 days from calving) and the rest of the lactation. The numbers in brackets are the respective STD.
significant effect on ICS consumption ($P \leq .01$), the results are presented per kg of the daily planned concentrates. Daily portions greater than 14 kg/d were planned only for the VMF cows (mostly at the beginning of lactation) because according to ARGOS system, based on the cow model (Hyink and Meyer, 1987) maximum daily concentrates supply is 14 kg/d. Because all VMF cows were actually milked 5 to 6 times a day at the beginning of the lactation, it was not necessary to allocate concentrates during non milking visits (decision no. 2, Table 1). The amount of candy in the daily portion remained constant throughout lactation, and in the different amounts of daily planned ICS.

Concentrates leftovers were measured weekly. On average 9.16% (SEM 2.409) and 5.5% (SEM 2.3900) of the allocated concentrates at the SU of portions smaller and bigger than 0.5 kg/visit respectively was not consumed (significant difference $P \leq .05$). Higher amounts of leftovers were recorded at the MU: 13.18% (SEM 6.640) of all ICS allocated. The only significant effect on the concentrates leftovers, found by Wald test statistics, was the higher amount of concentrates allocated at the SU.
3.4. SU time budgeting

Each SU was occupied on average for 11.15 h/d (SEM .4085). The SU duration comprises 4 sub-durations: I) the time from when the cow enters the SU until the first portion of ICS (if any) is allocated. Its mean duration is 1.67 min/visit (SEM .01866). This duration is a mainly a result of the hardware communication configuration which was used during the experiment. II) The time the cows were allocated concentrates. Mean concentrates allocation duration per visit, divided into milking frequency performed are presented in Table 2. The relatively longer duration for the VMF cows, compared to the FMF, is the result of the planned daily ICS which was always higher for VMF cows (with the same milking frequency) than for the FMF group. III) Waiting time is the time from when the last portion of ICS was allocated at the SU until the SU exit gate was opened. A distinction has to be made between milking and non-milking visits. Table 3 details the waiting time at the SU. The non-milking SU waiting time includes events in which the space between the SU and the MU (B, Fig. 1) was occupied and the cow could not be sent out. IV) The SU exit duration is the time from when the exit gate was opened until it was closed again and the SU was available for a new cow.

Table 2. Teat cup attachment duration by the milking robot, net milking machine duration and concentrates allocation duration per one visit at the SU. The results are divided by applied milking frequency and experimental groups. The results for twice a day milking and very high milking frequency for the FMF group are not presented due to too small numbers of observations.

<table>
<thead>
<tr>
<th>experimental group</th>
<th>milking frequency</th>
<th>milking robot attachment, min/milking</th>
<th>net milking machine time, min/milking</th>
<th>concentrates allocation duration at the SU, min/visits</th>
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Means within columns with different superscript differ (P ≤ .05)
Means within columns with different superscript differ (P ≤ .01)
Table 3 details the SU exit duration divided into the VMF and FMF groups for milking and non-milking visits. During non-milking visits, the VMF cows left the SU quicker than the FMF cows ($P < .05$). In both groups, the time taken to leave the SU to go to the MU compared to that taken to go to the feeding area was three time shorter ($P < .01$).

The DCMS assumed that the first 10 d should be treated as the adaptation phase to the cows. Fig. 9 presents the daily mean of herd visits to the SU, applied milking frequency and milkings. All three variables reach a relatively stable pattern after day 10 from calving.

3.5. MU time budgeting

The duration of one AMS milking event comprises 5 sub-durations. I) The passage duration between the SU and the MU: this duration was affected by group, stage of lactation or applied milking frequency. Table 4 presents the passage time only for milking visits for the two lactation stages. The differences between the two lactation stages were greatest compared to the differences due to other factors such as experimental groups, or the different applied milking frequency. II) The time from when the cow enters the MU until the milking robot starts the teat cup attachment process. Mean time was .45 min/milking (SEM .0184). Small differences (10 sec, $P < .05$) were found between the first 10 d and the rest of the lactation. III) The mean duration of the teat cup attachment by the milking robot was 2.46 min/milking (SEM .2298, Table 2) IV) The net milking machine duration is presented in Table 2, divided into the different milking frequencies applied.

Table 3. SU occupation and waiting duration (the time between last concentrates portion until SU exit gate is opened) divided into milking and non-milking visits. SU exit duration (the duration from when SU exit gate is opened until the SU is available again for the next cow) divided by experimental groups and milking and non-milking visits.

<table>
<thead>
<tr>
<th></th>
<th>SU waiting</th>
<th>SU occupation</th>
<th>SU exit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min/visit</td>
<td>min/visit</td>
<td>FMF group min/visit</td>
</tr>
<tr>
<td>milking visit</td>
<td>mean</td>
<td>7.07$^a$</td>
<td>12.40$c$</td>
</tr>
<tr>
<td></td>
<td>S.E.</td>
<td>.1628</td>
<td>.4197</td>
</tr>
<tr>
<td>non-milking visits</td>
<td>mean</td>
<td>2.34$^a$</td>
<td>9.91$d$</td>
</tr>
<tr>
<td></td>
<td>S.E.</td>
<td>.1624</td>
<td>.4157</td>
</tr>
</tbody>
</table>

$^{a,b}$ Means within columns with different superscript differ ($P \leq .001$)
$^{c,d}$ Means within columns with different superscript differ ($P \leq .01$)
$^A$ Means within rows with different superscript differ ($P \leq .05$)
Two models were used to test the effects on the milking duration and milk yield for each milking visit. The interval since last milking, parity and attachment duration were taken as fixed effects for both analyses (Table 2). The interactions between cows, attachment duration and the interval since last milking were taken as random effects. In the milking duration model, the milk yield variable was taken both as a fixed and as a random factor with the assumption of a linear relationship between milk yield and milking duration (see net milking machine duration, Table 2). As expected, the milk yield increases as the intervals since the last milking become longer ($P < .05$). Heifers yield significantly less than cows ($P < .05$). The relation between 5 levels of attachment duration to milk yield and milking duration per one milking are presented in Fig. 10. The longer the attachment duration, the less the duration of milking. The milk yield increases until the attachment duration of 3 min and then decreases. V) The duration from the end of the milking until the MU was available again for a new cow. The mean time was 2.57 min/milking (SEM .1026). A small difference in exit MU duration mainly due to stage of lactation were found (Table 4).
Fig. 10. Mean daily milk yield per milking (*), net milking machine time per milking (•) and the mean ration between MY and net milking machine time per milking (■) divided for five levels of automatic milking robot teat cup attachment duration.

Table 4. MU events durations, divided by stage of lactation: adaptation period, first 10 days after calving and the rest of the lactation.

<table>
<thead>
<tr>
<th></th>
<th>passage time between SU and MU, min/milking</th>
<th>milking robot attachment, min/milking</th>
<th>leaving MU after end of milking, min/milking</th>
</tr>
</thead>
<tbody>
<tr>
<td>first 10 days after calving</td>
<td>mean 1.63a</td>
<td>2.684c</td>
<td>2.75c</td>
</tr>
<tr>
<td></td>
<td>S.E. .0393</td>
<td>.1652</td>
<td>.146</td>
</tr>
<tr>
<td>the rest of the lactation</td>
<td>mean .98ab</td>
<td>2.23d</td>
<td>2.37d</td>
</tr>
<tr>
<td></td>
<td>S.E. .08</td>
<td>.1062</td>
<td>.089</td>
</tr>
</tbody>
</table>

Means within columns with different superscript differ (P ≤ .01)
Means within columns with different superscript differ (P ≤ .05)
4. Discussion

The full implementation of the individual planned milking frequency and ICS is dependent on
the cows' behaviour, system performance and the interaction between the two.

4.1. The DCMS and the AMS

System dependent factors are those which are related to the facilities, irrespective of the cows.
In our system prototype, the communication between the DCMS PC and the gates and self feeder
controller was not optimal. For this reason the time from the cows' entry into the SU until
implementation of the DCMS decision was too long. The DCMS could not control the SU gates and
the self-feeders on-line. The SU concentrates decision could be revised only if another cow entered
the second SU. Then the decision was calculated based on running values which evaluated the
expected waiting time at the SU and expected milkings until the end of the day (Eq. 1,2,3,
Appendix E). Hence, not all planned ICS could be allocated if the MU was free before the expected
time, or if the cow did not attend according to the planned milking regime. The DCMS needs to
control the self-feeders and gate controllers. The results confirm that there is enough time to
allocate all planned ICS at the SU while the cow is waiting for milking. The negative effects of the
system failures (milking robot mal-functioning and communication errors) on the visiting index and
as a consequence on the mean daily applied milking frequency and ICS allocation are obvious.
Individual analysis supported the assumption that unjustified rejection of cows from milking
contributes significantly (P < .05) to a low rate of applied milking frequency.

4.2. The behaviour of the cows: visiting pattern to the SU and adaptation

The cows' behaviour also contributes to the AMS performance. None of the individual analyses
showed any effects on cow behaviour from experimental groups and parities. The significantly
longer SU exit time between milking and non milking visits (Table 3) which was also reported by
Devir et al. (1995a,b) suggests that cows prefer the MU to the herd. Our results revealed similar
relation between passage time with and without ICS to that reported by Metz et al., (1991). The
duration of the passage time between the SU and MU was effected significantly by the amount
of ICS supplemented at the SU. High amounts of ICS resulted in relatively longer passage duration
(P ≤ .01). In addition, waiting time at the SU longer than 1 min resulted in shorter passage time
(Ps .01). It is possible that a mechanical device might accelerate cow traffic but this could have a
negative effect on the cows' welfare.

The cows had never been milked in an AMS before the experiment. It is therefore possible to
evaluate the adaptability of the cows to the AMS environment. Significant differences in the
individual mean of passage time between MU and SU between first 10 days and the rest of the
lactation for period (Table 4) strengthen the hypothesis that cows can be considered as having
adapted the AMS after 10 days.

Our results confirm former reports from Devir et al., (1995b). Individual events such as oestrus
and clinical lameness were found to have significant negative effects locally in time on the applied
milking frequency, with a consequently low number of visits to the SU.

The distribution of the intervals between successive visits to the SU confirms a former report
of Devir et al., (1995b) that milking cows in AMS based on voluntary visits to the SU, should not
be problematic for a milking frequency up of to 4 times a day.

Most of the cows visited the SU at least once in each time window. There were hardly any cases
in which more than two cows had to be brought and the farmer had to wait near the SU until it
was free. Thus, it is suggested that even given a very high milking frequency, of 5-6 times a day,
if no more than 2 cows need to be brought once in a while, this should not present any
management problems in the dairy.

The cows did not come back frequently after high ICS or milking rewarded visits. Un-rewarded
visits and low ICS visits were followed by more frequent visits to the SU. Unjustified unrewarded
visits, especially those which involved too long a waiting time at the SU before milking, and a
small amount of ICS led to too many short interval visits to the SU. According to the results of the
individual analysis, which evaluated the different effects on the interval between successive visits
to the SU it might be suggested that the cows’ short-term memory about what happened to them
in the recent past, e.g. the last visit, is stronger than other factors such as parity, and milking
frequency.

A high number of short interval visits overloads the SU and slows down cow traffic. It is
therefore recommended that at least two MU should be used, which might be with the same
milking robot. The ratio of two SU to one MU is adequate.

Because the only explanation for the high ICS left-over at the MU was the high amount of ICS
allocated at the SU, further research and analysis is needed to evaluate the relation between ICS
allocation at the SU and the MU in the AMS dairy.

4.3. Milking at the MU

Despite the fact that the experimental setup plan was to reduce the teat cup attachment time
to two min, the milking robot teat cup attachment time was too long. During the experiment the
daily rate of automatic attachment reached 69% (±30) of all milkings and the mean attachment
duration was therefore too long.

Our results might suggest that for up to 3 min the process of attachment acts as a stimulation
factor on the udder, which might cause the milk yield to increase. A longer attachment time might lead to incomplete milking and a reduction in milk yield (Rasmussen, 1994). The model applied to milk yield and milking machine time was also used for the individual ratio between milk yield and milking duration, which might be treated as a mean milk flow. These results might provide a better explanation for the milk yield decrease after three min of teat cup attachment process (Fig. 10). All the above might suggest that for up to two min of attachment the loss of time due to the attachment duration is compensated for by shorter milking time and possibly a complete milking. However, further analysis based on individual measurements of milk flows for each quarter of the udder are needed.

4.4. System capacity

Our results suggest that the mean MU occupation duration might be reduced by improving the speed of the teat cup attachment process, and accelerating the cow in the exit from the MU. It is believed that the idle time between the MU and the SU cannot be much reduced. This way one MU visit duration is estimated as between 6 and 8 min, mainly dependent on the cow’s milking duration. Given daily MU maintenance and cleaning procedures of about two h, the capacity of one MU under optimal conditions is estimated as between 130 and 180 milking/d.

The SU occupation during non milking visits was too long mainly because of too long a waiting time. Improvement of the gate control system might decrease the SU occupation duration. Reducing the SU waiting time would decrease the number of too long waiting time visits.

5. Conclusions

It is a practical management procedure to apply an individual high milking frequency and concentrates regime allocation to a dairy herd based on voluntary visits to the milking robot site. The requirement that all cows attend the SU at such intervals that allows them to be milked as planned, according to the time window principle, was almost fully achieved. The results indicate that on average all cows could be milked 4 times a day without needing to bring any cow to the SU.

A high rate of short interval visits which overload the SU should be avoided. Because of the DCMS prototype failures, too many cows were unjustifiably rejected and the planned milking frequency was not fully achieved for all cows. It is recommended that at least two MU be used for one group of cows, to avoid unrewarded visits which cause too frequent subsequent visits to the SU.

Not all cows were allocated ICS as planned because of the inability of the DCMS prototype to adjust ICS decisions on-line. However, there is enough time to allocate all planned concentrates
during milking, and waiting time at the SU before milking. The DCMS should directly control all gates, self-feeders and milking robot controllers.

Our results show that 130 to 180 milkings a day can be achieved in a system comprising one MU and two SU. The ratio of two SU for each MU is recommended for optimal cow traffic and to ensure enough time to allocate high amounts of daily ICS.

The relations between milking robot attachment time, milk yield and milking duration suggest that an attachment time up to three min, might serve as a stimulation phase, while an attachment time longer than 3 min decreases milk yield. Further analysis is needed to determine the exact relations between milk yield, milking duration and attachment time.

References


**Appendix A: daily planned concentrates supply**

The daily concentrates allocation for the experimental groups FMF and VMF for the first days from calving and the rest of the lactation.

<table>
<thead>
<tr>
<th>Group</th>
<th>days from calving</th>
<th>heifers kg/day</th>
<th>cows kg/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMF</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2 - 7</td>
<td>+ .5 each day</td>
<td>+ .5 each day</td>
</tr>
<tr>
<td></td>
<td>8 - 12</td>
<td>+1.0 each day</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>8 - 14</td>
<td>+ 1.0 each day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the rest of the lactation</td>
<td>according to the &quot;ARGOS&quot; system (Kroeze and Oving 1988)</td>
<td></td>
</tr>
<tr>
<td>VMF</td>
<td>1 - 14</td>
<td>(10 + day pp) * .6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the rest of the lactation</td>
<td>according Fuzzy-logic expert system, Grinspan et al., (14) and Maltz et al., (25)</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B: forage composition

Forage composition according to analysis made by the Oosterbeek Bedrijfslaboratorium voor Grond-en Gewasonderzoek, The Netherlands.

<table>
<thead>
<tr>
<th>dates of new forage clamps</th>
<th>1.8.93</th>
<th>8.1.94</th>
<th>1.3.94</th>
<th>1.8.93</th>
<th>22.11.94</th>
<th>1.8.93</th>
</tr>
</thead>
<tbody>
<tr>
<td>component</td>
<td>grass</td>
<td>grass</td>
<td>grass</td>
<td>corn</td>
<td>corn</td>
<td>sugar-</td>
</tr>
<tr>
<td>grass silage</td>
<td>silage</td>
<td>silage</td>
<td>silage</td>
<td>silage</td>
<td>silage</td>
<td>beet</td>
</tr>
<tr>
<td>component, % as fed</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>25</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>dry matter, g/kg</td>
<td>368</td>
<td>418</td>
<td>520</td>
<td>359</td>
<td>354</td>
<td>882</td>
</tr>
<tr>
<td>crude protein, g/kg roughage DM</td>
<td>244</td>
<td>219</td>
<td>240</td>
<td>69</td>
<td>74</td>
<td>94</td>
</tr>
<tr>
<td>energy, Kcal/kg DM</td>
<td>1651</td>
<td>1534</td>
<td>1625</td>
<td>1605</td>
<td>1509</td>
<td>1653</td>
</tr>
<tr>
<td>DVE¹, g/kg DM</td>
<td>79</td>
<td>71</td>
<td>91</td>
<td>48</td>
<td>42</td>
<td>103</td>
</tr>
<tr>
<td>OEB², g/kg DM</td>
<td>117</td>
<td>89</td>
<td>95</td>
<td>-36</td>
<td>-25</td>
<td>-68</td>
</tr>
<tr>
<td>crude fiber, g/kg DM</td>
<td>212</td>
<td>230</td>
<td>230</td>
<td>184</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADF, g/kg DM</td>
<td>238</td>
<td>291</td>
<td>276</td>
<td>202</td>
<td>236</td>
<td>233</td>
</tr>
<tr>
<td>NDF, g/kg DM</td>
<td>403</td>
<td>494</td>
<td>450</td>
<td>370</td>
<td>411</td>
<td>450</td>
</tr>
<tr>
<td>K, g/kg DM</td>
<td>30.2</td>
<td>22.0</td>
<td>40.0</td>
<td>8.7</td>
<td>10.9</td>
<td>7.6</td>
</tr>
<tr>
<td>Ca, g/kg DM</td>
<td>5.3</td>
<td>7.4</td>
<td>7.2</td>
<td>2.2</td>
<td>2.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Mg, g/kg DM</td>
<td>2.6</td>
<td>2.5</td>
<td>2.4</td>
<td>1.1</td>
<td>1.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Na, g/kg DM</td>
<td>5.6</td>
<td>7.5</td>
<td>4.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>1.1</td>
</tr>
<tr>
<td>P, g/kg DM</td>
<td>5.4</td>
<td>3.5</td>
<td>4.7</td>
<td>2.0</td>
<td>2.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

¹ True protein digested in the small intestine
² Rumen degradable protein balance
## Appendix C: data acquisition and utilization.

The data which was used during the experiment divided by type of acquisition, data type, location of acquisition and utilization.

<table>
<thead>
<tr>
<th>type of acquisition</th>
<th>data type</th>
<th>location of acquisition</th>
<th>utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>on-line, data from calving</td>
<td>body weight</td>
<td>SU data base</td>
<td>individual evaluation of daily milking frequency and ICS</td>
</tr>
<tr>
<td>on-line, data from calving</td>
<td>milk yield</td>
<td>MU data base</td>
<td>individual evaluation of daily milking frequency and ICS</td>
</tr>
<tr>
<td>on-line, data from calving</td>
<td>ICS consumed data base</td>
<td>SU,MU</td>
<td>individual evaluation of daily milking frequency and ICS</td>
</tr>
<tr>
<td>on-line</td>
<td>time events:</td>
<td>SU</td>
<td>1. last three days running means of individual SU visits, occupation and passages occurrences and duration</td>
</tr>
<tr>
<td></td>
<td>1. SU entrance</td>
<td></td>
<td>2. milking priority (see Table 2)</td>
</tr>
<tr>
<td></td>
<td>2. start of ICS at SU</td>
<td></td>
<td>3. system capacity</td>
</tr>
<tr>
<td></td>
<td>3. end of ICS at SU</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. opening SU exit gate and activating SU &quot;pusher&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. closing SU exit gate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>on-line</td>
<td>time events:</td>
<td>MU</td>
<td>1. last three days running means of individual MU visits, occupation and idle occurrences and duration</td>
</tr>
<tr>
<td></td>
<td>1. MU entrance</td>
<td></td>
<td>2. milking priority (see Table 2)</td>
</tr>
<tr>
<td></td>
<td>2. start of tea cups attachment</td>
<td></td>
<td>3. system capacity</td>
</tr>
<tr>
<td></td>
<td>3. start of milking</td>
<td></td>
<td>4. milking frequency performed</td>
</tr>
<tr>
<td></td>
<td>4. end of milking</td>
<td></td>
<td>5. milking duration</td>
</tr>
<tr>
<td></td>
<td>5. MU exit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>daily</td>
<td>1. planned milking frequency</td>
<td>DCMS output</td>
<td>daily evaluation of milking frequency and ICS (production and behavioural performance)</td>
</tr>
<tr>
<td></td>
<td>2. planned ICS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>on-line</td>
<td>1. Individual forage/water trough entrance</td>
<td>individual forage/water trough</td>
<td>further analysis</td>
</tr>
<tr>
<td></td>
<td>2. individual forage/water trough exit</td>
<td></td>
<td>production potential (Maltz and Metz, 1994)</td>
</tr>
<tr>
<td></td>
<td>3. forage/water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>twice a week</td>
<td>milk composition</td>
<td></td>
<td>individual daily milking frequency and ICS</td>
</tr>
<tr>
<td>once a week</td>
<td>forage dry matter content</td>
<td>at the experimental farm</td>
<td></td>
</tr>
<tr>
<td>periodically</td>
<td>forage and concentrates composition</td>
<td>feed composition laboratory</td>
<td>evaluation of individual daily milking frequency and ICS</td>
</tr>
<tr>
<td>routinely</td>
<td>lameness, oestrus, mastitis, parity, calving date</td>
<td>&quot;ARGOS&quot; dairy management system</td>
<td>daily evaluation of ICS and milking frequency</td>
</tr>
</tbody>
</table>
**Appendix D: milking intervals**

The minimum, maximum and fetching intervals since last milking for the different planned MF, divided by experimental groups and lactation stage. According to the fetching intervals, the DCMS lists 4 times a day the cows which are recommended to be brought to the MU by the farmer.

<table>
<thead>
<tr>
<th>planned milking frequency, milkings/d</th>
<th>FMF group, throughout experiment</th>
<th>VMF group, First 10 days PP</th>
<th>VMF after first 10 days PP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>maximum milking interval, h</td>
<td>maximum and fetching interval, h</td>
<td>maximum milking interval, h</td>
</tr>
<tr>
<td>2</td>
<td>10.0</td>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td>3</td>
<td>6.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>4</td>
<td>7.0</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td>5</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>6</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Appendix E: individual on-line concentrates supplementation calculations**

General:
The day is logically divided into six time windows $\text{tw}_i$, 4 h each, starting at midnight, $i = 1,2,3,4,5,6$.
The index $i_{\text{remainder}}$ represents the number of time windows left until the end of the day.

Notation:
- $\text{daily\_planned\_ics}$: The daily individual planned ICS, output of the daily update of the DCMS.
- $\text{expected\_su\_wait}$: The time the cow is expected to wait in the SU until she can be sent out to the MU. This duration is calculated each time a cow enters the SU. It comprises $\text{mu\_occup}$ of a cow at the MU (if any), and the $\text{expected\_su\_wait}$ of a cow at the second SU with higher priority (if any).
- $\text{mu\_occup}$: The expected MU occupation time. This duration is calculated daily based on a running mean of the last three days MU occupation duration.
- $\text{milk\_ics}$: The concentrates allocated at the MU during milking.
- $\text{su\_ics}$: The concentrates allocated at the SU.
- $\text{candy}$: A $\text{su\_ics}$ portion of 100 gr.
- $\text{supercany}$: The concentrates allocated at the SU if the cow is expected to wait for milking more than 5 min.
- $\text{ics\_consumed}$: The ICS which had already been allocated from midnight until time of decision.
making.

\[\text{milk}_{ics\_disp} \]

dispensing rate at the MU self feeder. The ICS are dispensed in portions of 100 gr each. The dispensing rate can be changed by allocating 100 gr portions at different time intervals. Minimum time interval for \(\text{milk}_{ics}\) is 20 sec.

\(l\)

The number of the time windows, \(i = 1,2,3,4,5,6\).

\(l_{\text{remainder}}\)

The number of the time windows until the end of the day, \(l_{\text{remainder}} = 1,2,3,4,5\).

\(\text{milk}_{tw[i]}\)

The milking time windows according to the individual planned milking frequency.

\(N\text{milk}_{tw[i]}\)

The non-milking time windows.

\[
\begin{align*}
\text{milk}_{ics} &= \begin{cases} \\
\frac{\text{Daily}_\text{planned}_ics - \text{ics}_\text{consumed}}{100[gr]} - 100[gr] + \sum_{j=1}^{l_{\text{remainder}}} \text{milk}_{tw[j]} - 100[gr] \end{cases} \\
\text{where} \\
\text{milk}_{ics} &\leq 3900[gr] \\
\text{milk}_{ics} &\geq 100[gr] \\
\text{milk}_{ics} &\leq \frac{\text{mu}_\text{occup} \times 100[gr]}{20[sec]} \end{align*}
\]

(1)

\[
\text{supercandy} = \begin{cases} \\
\frac{\text{expected}_\text{su}\_\text{wait} \times 100[gr]}{20[sec]} \end{cases} \\
\text{only if} \\
5[\text{min}] \leq \text{expected}_\text{su}\_\text{wait} \leq 25[\text{min}] \\
\text{where} \\
\text{supercandy} &\geq 100[gr] \\
(m\text{ilk}_{ics} - \text{supercandy}) &\geq 500[gr] \end{cases}
\]

(2)
\[
\begin{align*}
\text{su}_{\text{ics}} & = \begin{cases} 
\frac{\text{Daily}_\text{planned}_\text{ics} - \text{ics}_\text{consumed} - \sum_{j=1}^{\text{num\_booster}} \text{milk}_\text{tw}[j] \ast \text{mu}\_\text{occup} \ast 100 \text{[gr]}}{20 \text{[sec]}}}{\sum_{j=1}^{\text{num\_booster}} \text{n}\text{milk}_\text{tw}[j]} \end{cases} \\
\text{where} & \\
\text{su}_{\text{ics}} & \leq 3000 \text{[gr]} \\
\text{Only when} & \\
\text{Daily}_\text{planned}_\text{ics} - \text{ics}_\text{Consumed} - 4000 \text{[gr]} & \ast \left( \sum_{j=1}^{\text{num\_booster}} \text{milk}_\text{tw}[j] \right) > 0
\end{align*}
\]
Chapter 6

Dairy cow performance under full individual automatic management in the milking robot farm

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Abstract

The future prospects offered to the farmer by the integration of the milking robot into the dairy are beyond that of release from constant milking activity every day. A dairy control and management system provides the possibility of increasing production efficiency by combining individual milking and feeding strategies. It is expected that irregularities, as well as system failures, may occur during long-term operation of automatic milking systems (AMS).

The purpose of this 7 month trial was to examine the long term operation of an AMS management routine using available and appropriate technology. The individual approach was tested by applying to each cow individual management decisions on her milking frequency and concentrates supplementation. These decisions responded to actual performance. The production performance of three groups was compared: I) cows milked twice daily in a conventional milking parlour, and fed concentrates according to normal Dutch standards, II) cows milked in a milking robot three times daily throughout the experiment and fed concentrates according to normal Dutch standards and III) cows milked in a milking robot where their individual daily milking frequency (from 2 to 6 times day) and concentrates allocation were continuously evaluated, based on their performance.

Because the dairy control and management system operated was a prototype, the planned milking and concentrates regime could not always be fully implemented. The results obtained from the two milking robot groups indicated that production efficiency of the variable high milking frequency group was higher than the fixed milking frequency group. The way the system made and implemented decisions suggests that AMS has the flexibility to affect production through MF together with the capacity to back it up by individual concentrates allocation. AMS may therefore be considered as a useful tool for the farmer not only in its ability to relieve him of his ties to the milking routine, but as a key to improving management practice.

Key words: control, dairy, milking frequency, milking robot, production

Abbreviation key: AMS = automatic milking system, ICS = individual concentrates supplementation, MF = milking frequency, MU = milking, SU = selection unit

1. Introduction

The farmer can benefit in two ways from using the milking robot: he can be physically released from the milking process and he also gains a management tool which can increase production efficiency through manipulation of the milking frequency (MF), and individual concentrates supplementation (ICS) (Devir et al. 1993a, 1995c).
It has been shown that when a milking robot is connected to a self-feeder station as an automatic milking system (AMS) it can be controlled in such a way as to impose a conventional (twice or three times daily) or high MF (Devir et al., 1995a,b). However, no long term trials to check the AMS concept over a significant part of the lactation period starting at the calving date, have been reported yet. It is reasonable to assume that this technology will penetrate the dairy industry initially as a "milking activity relief" for the farmer. This requires system reliability in executing conventional know-how regarding MF and ICS (Devir et al., 1995c). However, it is expected that irregularities as well as system failures may evolve during the long term operation of AMS (Devir et al., 1995b,d). Analyzing the cows' reaction (from both performance and health perspectives) to system failures, is a necessary step prior to adopting this technology as a dairy routine.

The demand for the application of AMS as a management tool is also more complicated. Guidelines have to be drawn up for MF and ICS which refer to each cow's performance. These guidelines will dictate the MF and ICS to be applied to any cow at any given time on a specific farm. This can be regarded as an individual management approach (Maltz and Metz, 1994).

By manipulating MF we can increase production (Hillerton, 1992, Bar-Peled et al., 1992). The increase in production can be supported by appropriate ICS to increase ration density (Maltz et al., 1992). The flexibility of AMS permits the application to each cow of different MF and ICS which respond to the cow's individual performance (Devir et al., 1993a). This approach has not yet been thoroughly tested under any management strategy. So, in addition to the operational and control difficulties (Devir et al., 1995d), the individual approach confronts us with the problem of the guidelines according to which it will be operated. Such guidelines must also be examined (Maltz and Metz, 1994).

The purpose of this trial was to examine the long-term operation of an AMS management routine under two concepts: a) fulfilling the conventional demands of MF and ICS while analyzing the cows' responses to irregularities and system failures that might occur when AMS is operating continuously. b) exploiting the flexibility offered by the technology in use in order to test the individual approach by applying to each cow individual management decisions on MF and ICS that respond to actual performance. The daily milking and concentrates allocation was automatically controlled by a dairy control and management system prototype developed in IMAG-DLO (Devir et al., 1993a, 1995d)

2. Material and methods

2.1. The experimental groups

Three groups of cows were involved in this field test. All the cows were cross bred
Holstein-Friesian. The Milking Parlour (MPAR) group comprised 17 primiparous and 15 multiparous cows, all having calved between January 22th 1993 and November 11th 1993. These cows were milked twice a day at 05:30 and 16:00 in a conventional herring-bone milking parlour with 2x4 milking stalls.

Two groups, which differed in their MF and ICS management, were milked in an AMS from August 21th, 1993 until March 31th, 1994. The first colostrum milking took place at the maternity barn. Then, if the cow had no clinical abnormalities (such as retained placenta), they were moved into the AMS group and started to be milked and supplemented with concentrates according to one of two strategies:

I) The fixed MF (FMF) AMS group comprised 2 primiparous and 8 multiparous cows. All cows calved between August 21th to September 19th 1993. This group was to be milked 3 times a day in a fully-controlled AMS, based on voluntary visits to the milking robot site (Devir et al., 1995a).

II) The variable milking frequency (VMF) group comprised 4 primiparous and 10 multiparous cows, who had calved between August 23th and November 6th 1993.

The AMS cows (FMF and VMF groups) were not milked at the AMS throughout all the lactation period. On April 1st, 1994 all AMS cows were moved to traditional management. They were then milked twice a day.

All groups were kept in the same barn, which was divided into two separate sections. The MPAR cows were kept in the section which was further from the AMS. These cows were driven to the milking parlour through a passage external to the barn. The AMS cows were allocated to the second section, which was closer to the AMS. These cows could report voluntarily to a selection unit, installed before the milking unit. For more barn layout details, please refer to chapter 5 or Devir et al., (1995d,e).

The AMS cows were not inseminated before day 100 from calving to impose (as far as possible) standard conditions for comparison between the AMS groups. Oestrus observations took place daily at 08:00, 13:00 and 22:00. The cow was defined as in oestrus if she showed standing heat behaviour as described by Hurnik (1978).

2.2. Feeding management

All cows were fed forage containing 60% grass silage, 25% corn silage and 15% sugar-beet pulp. For full forage composition and energy content, refer to Table 1. The forage was available through two individual forage systems (Ipema and Metz, 1992). The system used by the MPAR comprised 8 individual feeding boxes and two individual water troughs. The other system, used by the FMV and VMF cows, comprised 12 individual forage boxes and two water troughs. The AMS
cows had one extra water trough located in the lying area. In both forage systems, if the individual forage were empty, they were refilled with forage if needed each half-hour using a self-driven mixing wagon (Ipema and Metz, 1992; Devir et al., 1995d).

MPAR cows were supplemented concentrates at the feeding area via a self-feeder. All AMS cows were allocated concentrates only at the selection and milking units self-feeders. The MPAR and the FMF AMS cows were supplemented ICS according to the nutritional module of the ARGOS system (Kroeze, 1990). The ICS for the VMF cows was based on a fuzzy logic expert system design devised for timing the transfer of dairy cows from a high energy to a lower energy ration (Grinspan et al., 1994). The transfer decision is based on trends in milk production, body weight changes and interactions between them (Maltz and Metz, 1994). In the experiment described here this expert-system was modified exclusively for AMS conditions. Milking frequency and concentrates allocation recommendations were made daily on an individual basis. For more details on the AMS layout and management, refer to Devir et al., (1995d, 1995e).

Table 1: Forage composition according to analysis made by the Oosterbeek Bedrijfslaboratorium voor Grond- en Gewasonderzoek, The Netherlands.

<table>
<thead>
<tr>
<th>dates of new forage clamps</th>
<th>1.8.93</th>
<th>8.1.94</th>
<th>1.3.94</th>
<th>1.8.93</th>
<th>22.11.94</th>
<th>1.8.93</th>
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</thead>
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<tr>
<td>component</td>
<td>grass</td>
<td>grass</td>
<td>grass</td>
<td>corn</td>
<td>corn</td>
<td>sugar-</td>
</tr>
<tr>
<td></td>
<td>silage</td>
<td>silage</td>
<td>silage</td>
<td>silage</td>
<td>silage</td>
<td>beet</td>
</tr>
<tr>
<td>component, % as fed</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>25</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>dry matter, g/kg DM</td>
<td>368</td>
<td>418</td>
<td>520</td>
<td>359</td>
<td>354</td>
<td>882</td>
</tr>
<tr>
<td>crude protein, g/kg roughage DM</td>
<td>244</td>
<td>219</td>
<td>240</td>
<td>69</td>
<td>74</td>
<td>94</td>
</tr>
<tr>
<td>energy, Kcal/kg DM</td>
<td>1651</td>
<td>1534</td>
<td>1625</td>
<td>1605</td>
<td>1509</td>
<td>1653</td>
</tr>
<tr>
<td>DVE¹, g/kg DM</td>
<td>79</td>
<td>71</td>
<td>91</td>
<td>48</td>
<td>42</td>
<td>103</td>
</tr>
<tr>
<td>OEB², g/kg DM</td>
<td>117</td>
<td>89</td>
<td>95</td>
<td>-36</td>
<td>-25</td>
<td>-68</td>
</tr>
<tr>
<td>crude fiber, g/kg DM</td>
<td>212</td>
<td>230</td>
<td>230</td>
<td></td>
<td></td>
<td>184</td>
</tr>
<tr>
<td>ADF, g/kg DM</td>
<td>238</td>
<td>291</td>
<td>276</td>
<td>202</td>
<td>236</td>
<td>233</td>
</tr>
<tr>
<td>NDF, g/kg DM</td>
<td>403</td>
<td>494</td>
<td>450</td>
<td>370</td>
<td>411</td>
<td>450</td>
</tr>
<tr>
<td>K, g/kg DM</td>
<td>30.2</td>
<td>22.0</td>
<td>40.0</td>
<td>8.7</td>
<td>10.9</td>
<td>7.6</td>
</tr>
<tr>
<td>Ca, g/kg DM</td>
<td>5.3</td>
<td>7.4</td>
<td>7.2</td>
<td>2.2</td>
<td>2.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Mg, g/kg DM</td>
<td>2.6</td>
<td>2.5</td>
<td>2.4</td>
<td>1.1</td>
<td>1.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Na, g/kg DM</td>
<td>5.6</td>
<td>7.5</td>
<td>4.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>1.1</td>
</tr>
<tr>
<td>P, g/kg DM</td>
<td>5.4</td>
<td>3.5</td>
<td>4.7</td>
<td>2.0</td>
<td>2.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

¹ True protein digested in the small intestine  
² Rumen degradable protein balance
2.3. The individual VMF AMS milking and ICS guidelines

The guidelines of the management regime for the VMF cows were designed on the assumption that production can be increased by a higher MF for a short period. This is supported by appropriate ICS that increases ration density and prevents excessive tissue drain with its accompanying well known negative effects on the lactation curve (collapse) health and reproduction.

Regarding MF, we intended to exploit the carry-over effect of short term high MF after calving, described by Bar Peled et al., (1992), both by increasing production as well as dry matter intake (DMI) throughout lactation and by applying the lowest daily milking frequency.

Regarding ICS, we adapted the idea of supplementing cows according to their lactation potential i.e. the daily 4% fat corrected milk (FCM) production calculated as percentage of body weight (BW) (Maltz et al., 1992, Spahr et al., 1993). The maximal ICS was calculated as 60% of DMI for cows producing FCM of more than 8% of their BW, and the minimal ICS calculated as 40% of DMI for cows producing FCM of less than 5% of BW. It was therefore expected that ICS would increase as long as DMI and lactation potential increased. When BW stopped declining and FCM reached its peak, ICS was reduced by 1% of maximal intake a day as long as the FCM decline was as expected. ICS reduction was stopped when the FCM curve declined at a sharper rate than expected, and resumed when the FCM decline resumed its expected pattern. ICS was not reduced below a minimum of 40% of DMI.

The daily decision making process on ICS and MF for VMF cows was performed by a daily analysis of the individual performance data since calving, as described by Devir et al., (1995d) and Maltz and Metz (1994). DMI was calculated on a daily basis. The ICS adjustments were done twice a week. ICS was increased only if the cow had consumed all the daily allocated concentrates ration.

The ICS routine was carried out as follows: All cows received 6 kg concentrates on the first day and the amount was increased daily by 0.6 kg up to 14 days. Then linear regression was performed daily for the last 14 days of DMI, when it was calculated each day as a 3-day running average. Then an extrapolation was done for day 15 and ICS was calculated as a percentage of the extrapolated DMI value. Cows that produced FCM 5-6% of BW were allocated concentrates with 45% of the predicted DMI. Those producing between 6-7% of BW, received 50% of the predicted DMI, and those between 7-8% of BW received 55% of the predicted DMI.

Milking frequency guidelines were designed so that the cow would be milked 6 times daily until peak FCM production, and then MF was reduced gradually to three times daily, following the same criteria of lactation curve decline as for ICS reduction. When the lactation curve decline sharpened, MF reduction was withheld and resumed after the FCM curve decline became more
Dairy cow performance in the milking robot farm

There was always at least a one-week interval between MF reductions. For more details regarding the physiological interpretation of FCM and BW changes (according to which these guidelines were drawn up) and for information on daily performance data handling to identify the proper time for management changes, see Maltz and Metz (1994).

2.4. Data acquisition and analysis

The MY data used for the MPAR cows is the data which is usually recorded at a dairy with automatic milk meter facilities. During the AMS experimental period, the FMF and VMF cows' MY data were measured at each milking at the milking robot site. The AMS cows were milked at different intervals between successive milkings (Devir et al., 1995c). In order to unify MY data for the purposes of analysis, the MY production was corrected for 24 h of production. The time interval between the time of the last milking on the previous day to the time of the last milking on the following day was calculated. Then the MY multiplied by the ratio of this time interval and 24 h.

The production analysis for comparing the MPAR and FMF cows' production performance was carried out using the Royal Netherlands Cattle Herdbook (NRS) routine milk checks. Because each cow has a different lactation period, all MY production data were corrected for 305 days of prediction in lactation, using means calculated within herd and lactation curves as described by Wilmink (1987) and Kroeze (1990). The milk composition for each milking during 24 h was sampled and analyzed twice a week. The analysis was carried out by a commercial laboratory for milk fat, protein, lactose and Somatic Cell Count (SCC). The milk fat and protein were averaged to a daily mean corrected for the amount of milking for each sample (2 to 6 samples a day). Then the 4% FCM was calculated based on daily MY and last fat known using the Eqn 1.

\[
FCM = 0.4 \times MY\,[kg] + \text{Fat}\,[\%] \times MY\,[kg] / 100 = 15
\]

For analysis and data presentation, Fat Protein Corrected Milk (FPCM) was calculated using the Eqn 2 (Korver, 1988).

\[
FPCM = (0.349 + 0.107 \times \text{Milk Fat}\,[\%] + 0.067 \times \text{Milk Protein}\,[\%]) \times MY\,[kg]
\]

The MPAR cows' body weight (BW) was not measured. The FMF and VMF cows' BW was measured each time the cows entered the selection unit (SU) before to the milking unit (MU). In 98% of all
visits to the SU the successive interval was shorter than 6 h. (Devir et al., 1995d). On average each cow appeared to be weighed 9.72 times a day (S.E. 0.5911). The measurements acquired during the day were averaged to one daily mean value. BW measured values were excluded if they were different in 1, 1.2 and 1.4 times the daily BW data standard deviation, when only 3, 4 and more than 4 daily BW measurements were available, respectively.

ICS was measured each time it was allocated to a cow at the SU or at the MU. Once a week leftovers from the SU and MU self-feeders were measured during milking visits. The forage was measured using the individual forage allocation system (Ipema and Metz, 1992). Body condition scores (BCS) were sampled by the same herdsman twice a week. Forage and ICS dry matter content were measured weekly. Each time a new clamp of forage was used, a sample was sent to the laboratory for composition analysis (Table 1). All reproduction and clinical events were recorded in the dairy management "ARGOS" (Kroeze, 1990) system when needed. Standing heat was observed three times daily. The results of twice a week palpation and milk progesterone were used to validate the day of the observed heat.

The AMS groups' data is based on the daily acquired data, summarized into daily values. Because there were only a few primiparous cows in the AMS group, data analysis was carried out excluding all heifers. One cow had severe mastitis at an early stage of the lactation. She was not culled, so that high capacity of the AMS was maintained, but she was removed from all data analysis and presentation. The analysis may be regarded as logarithmic analysis of variance. For all statistical analysis the REML routine of the statistical package Genstat 5.1 release 3.1 was used (Genstat 5 Committee, 1993).

3. RESULTS AND DISCUSSION

3.1. Fixed milking AMS vs MPAR

The AMS FMF group was to be milked 3 times a day. On a daily basis, cows were milked 97.8% (±21.97) and 106% (±18.88) of the planned milkings during the first 10 days from lactation, and the rest of the lactation, respectively (Fig. 1). Only 2% of all daily milkings recorded were days on which cows were to be milked only twice daily, mainly due to lameness or mastitis (Devir et al., 1995c). Because the system was controlled by a dairy control and management system prototype, some irregularities in applied MF occurred due to system failures (see below).
Fig. 1. Mean daily MF applied as percentage of planned for the different planned MF divided into the first 10 days of the lactation after calving separately for the FMF and VMF group, and the rest of the lactation for all AMS cows.

Fig. 2. Daily mean ICS allocated as percentage from planned divided by planned ICS [kg/day] for the FMF AMS group (•) and VMF AMS group (△).
According to the nutritional module of the ARGOS system, the maximal daily planned ICS cannot exceed 14 kg (Hyink and Meyer, 1988). It can be seen that the AMS cows did not consume the full ration when ICS was maximal and more than 13 kg/d (Fig 2). This is not the result of cows failing to consume the allocated amount, but rather the result of the system failing to provide it (Devir et al., 1995d). Fig. 3 shows the planned and allocated ICS for the FMF AMS cows on a scale of time after calving. It was mainly in the first stage of lactation that cows did not consume the planned ICS. The fact that the cows did not consume the planned ICS during the sensitive time of peak lactation could affect production (see below). Table 2 presents milk production values, corrected for 305 days of production, for MPAR and the FMF AMS group. No significant difference in production performance was found between the MPAR and the AMS FMF group. The AMS FMF cows were milked on average 207 (±8.84) days under AMS conditions during an average total lactation length of 271.7 (±86.97) days. Following that they were transferred to the conventional milking parlour to be milked twice daily. This caused a significant enhancement in the declining rate of lactation curve of some of the cows as can be seen in Fig. 4. This could explain the insignificant lower annual production of the AMS cows (Table 2).

Fig. 3. The FMF AMS group daily mean ICS allocated (•) and planned (line) on time from calving scale.
Table 2: Milk yield, fat and protein production, for the MPAR and FMF AMS groups. The values were corrected for 305 production days. All differences between two groups are not significant.

<table>
<thead>
<tr>
<th></th>
<th>MPAR group</th>
<th></th>
<th>FMF AMS group</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>std</td>
<td>mean</td>
<td>std</td>
</tr>
<tr>
<td>no. of cows</td>
<td>17</td>
<td></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>day in lactation</td>
<td>316.41</td>
<td>49.37</td>
<td>297.0</td>
<td>77.8</td>
</tr>
<tr>
<td>milk yield [kg]</td>
<td>9090.41</td>
<td>1576.9</td>
<td>8123.5</td>
<td>1456.0</td>
</tr>
<tr>
<td>milk fat [%]</td>
<td>4.78</td>
<td>0.66</td>
<td>4.92</td>
<td>0.51</td>
</tr>
<tr>
<td>milk protein [%]</td>
<td>3.53</td>
<td>0.21</td>
<td>3.56</td>
<td>0.18</td>
</tr>
<tr>
<td>milk fat [kg]</td>
<td>427.8</td>
<td>56.45</td>
<td>398.2</td>
<td>82.4</td>
</tr>
<tr>
<td>milk protein [kg]</td>
<td>318.4</td>
<td>45.67</td>
<td>288.6</td>
<td>56.3</td>
</tr>
<tr>
<td>FCM [kg]</td>
<td>10055.5</td>
<td>1359.9</td>
<td>9221.9</td>
<td>1709.8</td>
</tr>
<tr>
<td>FPCM [kg]</td>
<td>9885.0</td>
<td>1358.0</td>
<td>9030.3</td>
<td>1743.6</td>
</tr>
</tbody>
</table>

Fig. 4. Daily MY of three cows from the FMF AMS group on a time from calving scale. The arrows indicate the time the cows were moved to twice daily milkings in the milking parlour.
There was no significant difference in milk composition, nor in fat and protein production, between these two groups (Table 2). Higher production could be expected for the AMS cows that were milked three times daily when compared with the MPAR cows which were milked only twice. The fact that this expectation was not fulfilled can be explained partly by the fact that the AMS regime was not applied throughout the whole lactation period and the transfer to the conventional milking parlour caused a reduction in production (Fig. 4), and partly by the fact that AMS cows did not actually consume the planned maximal ICS (Fig. 2,3). We think that the AMS cows could have achieved a higher production level if the trial had lasted throughout the full lactation period and ICS had been improved.

A comparison of reproduction performance between the MPAR and AMS groups is summarized in Table 3. Despite the fact that AMS cows were not inseminated before day 100 in lactation there was no significant difference in days to pregnancy. This may suggest that when the AMS cows were inseminated they had a more suitable energy balance for conception than cows in the MPAR group that were inseminated earlier in lactation (Butler and Smith, 1989). This is also suggested by the number of inseminations per cow for each pregnancy. In the AMS FMF cows this ratio was lower (N.S.) than in the MPAR cows.

Table 3: Reproduction performance and number of disease events for the MPAR, FMF and VMF groups.

<table>
<thead>
<tr>
<th></th>
<th>MPAR group</th>
<th></th>
<th>FMFAMS group</th>
<th></th>
<th>VMFAMS group</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>number of cows</td>
<td>19</td>
<td>std</td>
<td>8</td>
<td>std</td>
<td>9</td>
<td>std</td>
</tr>
<tr>
<td>days to 1st insemination</td>
<td>79.59</td>
<td>26.05</td>
<td>116.2</td>
<td>a</td>
<td>19.17</td>
<td>117.7</td>
</tr>
<tr>
<td>days to pregnancy</td>
<td>112.24</td>
<td>46.35</td>
<td>135.7</td>
<td>26.04</td>
<td>124.6</td>
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<tr>
<td>number of inseminations</td>
<td>1.94</td>
<td>1.24</td>
<td>1.62</td>
<td>1.06</td>
<td>1.44</td>
<td>0.73</td>
</tr>
<tr>
<td>number of clinical mastitis events</td>
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<td>5</td>
<td></td>
<td>2</td>
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<tr>
<td>number of reproduction treatments</td>
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<td>-</td>
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<tr>
<td>number of other diseases</td>
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</table>

* means with different superscript within rows differ (P < 0.05)

There were several system failures during the trial that caused significant milking delays, resulting in cows being milked only twice or even once daily for as long as 24 hours (11 days out of 4689 daily records). Analysis of the consequences of these failures shows no long-lasting effect on production (Fig. 5a,b). No clinical problems were detected that could be related to the system.
Fig. 5a. Daily MY [kg] (■), forage intake [kg dmi] (□), ICS [kg dmi] (*) and milkings (line) for an AMS cow. The vertical line marks a day of a system failure.

Fig. 5b. Daily MY [kg] (■), forage intake [kg dmi] (□), ICS [kg dmi] (*) and milkings (line) for an AMS cow. The vertical line marks a day of a system failure.
failure. This suggests that cows are tolerant of short-term (up to 24 hours) failures when experiencing the irregular milking intervals that are typical of robot milking based on voluntary visits.

Clinical problems recorded during the trial (Table 3) show that the ratio of cases of mastitis and lameness relative to the number of cows participating was higher in the FMF AMS cows. Although the sample is small, the higher rate of udder problems in the FMF AMS may suggest one of three possibilities (or any combination of the three): 1) That udder problem occur because of irregular milking intervals. 2) That they are a result of the higher milking frequency. 3) That they are a result of cows being infected because they are milked by the same cluster. The problems of lameness could have resulted from the facilities and their lay out in the AMS barn. Steps to be climbed (to the SU) and the automatic closing gates (SU and MU) could have caused such problems. However the sample is too small to draw decisive conclusions for both mastitis and lameness.

It seems that the implementation of AMS into the dairy farm to fulfil the conventional requirements of milking and ICS can be achieved. With some improvements, the dairy control and management system (Devir et al., 1993a) will automatically execute a predetermined strategy with minimal involvement of manual work.

3.2. FMF vs VMF

The VMF regime should have performed 6 milkings a day from the first day of lactation for a period that differed for each cow, and was then to be gradually reduced. Unfortunately, an operational limitation during the introduction of the dairy control and management system prototype, occurring mainly at the beginning of the experiment, caused complications in controlling and executing the planned individual regimes. As a result the first cows that went into the trial were milked less frequently than planned during the first days after calving (Fig. 6a,7a). In addition, these cows were also allocated less ICS than planned (Fig. 6b,7b). Consequently we could expect that the individual management regime would have an incomplete or less effect on their performance (see below). Later in the trial we overcame the obstacles involved and the planned regime was fully implemented (Fig 8a,b and 9a,b ). We therefore analyzed the performance results separately for the first 10 days, bearing in mind that the effect of the first days' management could influence the rest of the lactation period.
Figure 6a: Three days running average of FPCM [kg] (ω), BW from initial BW [%] (Ω), DMI [kg] (*), planned milkings (line) and performed milkings (Δ) for a VMF AMS cow which entered the AMS herd in an early stage of the experiment.

Figure 6b: Three days running mean of daily forage intake [kg dm] (*), planned ICS [kg dm] (line) and allocated ICS [kg dm] (ω) for a VMF AMS cow which entered the AMS herd in an early stage of the experiment.
Figure 7a: Three days running average of FPCM [kg] (△), BW from initial BW [%] (□), DMI [kg] (☆), planned milkings (line) and performed milkings (●) for a VMF AMS cow which entered the AMS herd in an early stage of the experiment.

Figure 7b: Three days running mean of daily forage intake [kg dm] (☆), planned ICS [kg dm] (line) and allocated ICS [kg dm] (△) for a VMF AMS cow calved at the beginning of the experiment.
Fig. 8a. Three days running average of FPCM [kg] ( ), BW from initial BW [%] ( ), DMI [kg] ( ), planned milkings (line) and performed milkings ( ) for a VMF AMS cow, which entered the AMS herd in a late stage of the experiment. The data is presented for the AMS followed by the milking parlour period.

Fig. 8b. Three days running mean of daily forage intake [kg dm] ( ), planned ICS [kg dm] (line) and allocated ICS [kg dm] ( ) for a VMF AMS cow which entered the AMS herd at a late stage of the experiment.
Dairy cow performance in the milking robot farm

Figure 9a: Three days running average of FPCM [kg] (ω), BW from initial BW [%] (ω), DMI [kg] (ω), planned milkings (line) and performed milkings (|) for a VMF AMS cow, which entered the AMS herd at a late stage of the experiment. The data is presented for the AMS followed by the milking parlour period.

Figure 9b: Three days running mean of daily forage intake [kg dm] (ω), planned ICS [kg dm] (line) and allocated ICS [kg dm] (ω) for a VMF AMS cow which entered the AMS at a late stage of the experiment.
Performance data for the FMF (8 cows) and VMF (9 cows) groups are summarized in Table 4. All daily means are presented for the first 10 days after calving, i.e. the adaptation period of the cows to the AMS environment, for days 11 to 145 after calving, when all cows were milked under AMS conditions, and from calving until the time the cows were send for grazing and thereafter milked twice daily in the milking parlour. The table details daily mean intake, forage and concentrates and total dry matter intake, body weight after calving and on day 145 after calving, mean body condition scores and FCM and FPCM production. The ratio of dry matter intake to body weight and the ratio of FCM to BW are presented as an indication of production efficiency.

Daily FPCM for complete lactation was significantly higher in the VMF group. Since this difference was not recorded during the period when all cows were under AMS management (the first 145 days), it can be assumed that the higher FPCM production of the VMF cows throughout lactation, was the result of greater lactation persistency in the cows in this group. It seems that the guidelines of the individual management regime used in this trial did yield the expected carry-over effect of the MF (Bar Peled et al., 1992) and ICS at early lactation.

The FCM production per unit of BW was also significantly higher in the VMF cows. It seems that in this respect also an ICS based on production related to BW is an appropriate guideline for supplementing cows more efficiently than one based on milk production alone (Maltz et al., 1991, 1992; Spahr et al. 1993). We can also see that the aim of increasing DMI (Bar Peled et al., 1992) was achieved in the VMF cows, which consumed almost 2 kg DM more than the FMF group (Table 4). The higher DMI was mainly due to ICS. However, this did not reduce forage consumption which indicates that the timing of the increase and reduction in ICS during lactation was at the appropriate physiological stages as described by Maltz and Metz (1994). This higher consumption also contributed to body reserves. This can be concluded from the fact that the initial BCS of the VMF cows was lower than that of the FMF group, but after 147 days it was higher (Table 4).

The reproduction performance of the two AMS groups was very similar (Table 3). Apart from mastitis, there was no difference in clinical health problems, as can be seen from those recorded during the period that the cows were under AMS management (Table 3).

It should be stressed that these results were obtained when the guidelines for the individual approach had not been fully implemented due to technical difficulties. As described above, some of the VMF cows were milked and fed at ratios less than the guideline instructions. It is reasonable to suspect that this affected performance negatively and that, with improved AMS operation, the VMF cows' performance would have been better.
Table 4: Daily mean production performance for the FMF (8 cows) and VMF (9 cows) groups. Results are presented for the first 10 days after calving, the adaptation period of the cows to the AMS environment, days 11 to 145 after calving when all cows were milked under AMS conditions and from calving until the time the cows were sent for grazing and all milked twice daily in the milking parlour.

<table>
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<th>period within lactation</th>
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<th>VMF</th>
<th>difference between groups</th>
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### Table 4: Cont.

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<td>4.15</td>
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</table>

1. ICS is the daily mean concentrates allocation in dry matter values.
2. Forage in the daily mean intake measure by the individual forage system in dry matter values.
3. IBW is the BW measured at maternity within 2 h after calving.
4. BCS is the daily mean body condition scores which was measured twice a week by the same herdsman.
5. DMI is the daily mean dry matter ICS and forage intake.
6. FCM is a 4% fat corrected milk.
7. FPCM is protein fat corrected milk (Korver, 1988).
8. The DMI/BW is the mean daily total DMI divided by daily mean BW multiplied by 100.
9. PP is the ratio between daily FCM [kg] to mean daily body weight [kg] multiple by 100.
The AMS offers a wide range of operational guidelines (Devir et al., 1995c) for the farmer to select from. However, there are two main obstacles to be overcome before this strategy is offered to the industry. 1) There is not enough experience in the application of the individual approach in commercial dairies (Maltz and Metz, 1994). 2) Since it is beyond the capacity of the individual farmer to scrutinize and analyze performance data and do the appropriate calculations for frequent decisions, such decisions have to be taken automatically. This means that a computerized expert system has to be used. This expert system will use performance data as input and yield a decision as output. Recent publications describe such an expert system which was developed for cow transfer between feeding groups, and based on individual cow performance (Maltz et al., 1992; Grinspan et al., 1995). This expert system can be modified with the proper coefficients and limits to make decisions regarding MF and ICS.

The results obtained from the VMF cows, and the way the decision-making was performed, suggest that AMS can be used as a tool to improve management practice in addition to its capacity as a form of release for the farmer from the traditional milking routine.

4. Conclusions

It can be concluded that when the dairy control and management system operates smoothly, the milking robot can be incorporated into the dairy farm to perform the milking process without the farmer's involvement. This relieves the farmer of substantial physical labour and improves his quality of life. The results of the three times daily milkings suggest that with some improvements in concentrates rationing, and the lay-out of facilities, this regime is achievable. It is reasonable to assume that under a twice daily milking regime the system will function even better.

In addition, AMS possesses the flexibility to affect production through MF, together with the capacity to support it by ICS. It can therefore be utilized as a tool to make the dairy industry more efficient. More research is needed over at least two successive lactations to assess the potential of individual production control and its carry-over effect on the cows' production efficiency.

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robot milking and concentrates supply. Submitted to Journal of Agricultural Engineering Research.


Management planning and implementation
at the milking robot dairy farm.

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Submitted to the Computers and Electronics in Agriculture
Abstract

The milking robot (MR) is more than a tool to relieve the farmer of the substantial daily work associated with the milking process. Current technologies offer the possibility of increasing production efficiency by combining individual milking and feeding strategies.

Although the MR can be integrated into almost any type of dairy, e.g. small or big herds, with or without grazing, its use differs from one dairy to another. To benefit from the MR not just as a replacement for a milking parlour, but as a management application the farmer should first outline his strategic planning according to his needs and available facilities. On the planning horizon, his considerations comprise concentrates rationing, grazing (if it exists, and with or without indoor forage rationing), number of milkings per day (as reflected in herd size or milking frequency), facilities and labour. The planning is implemented and controlled at both operational and performance levels.

The farmer selects his strategic goals according to his operational methods. The dairy can operate from the basic level of replacing the milkers only, up to a fully-automatic controlled daily milking, feeding and cow traffic routine, with minimal involvement of the farmer. The degree of system management automation and individuality will be determined by the farmer’s choice of these methods.

Continuous evaluation of the cow’s performance is incorporated into an individual production profile including such characteristics as milk production, milking frequency, concentrates allocation, and body reserve balance. Defining the relationships between these characteristics would enable planning of an individual production regime.

The implementation of the planned individual production regime, and its control in the MR dairy, is possible using three management functions: milking frequency, individual concentrates allocation and cow traffic. The on-line control of these management functions permits an increase in production efficiency and an improvement in cow welfare.

Key words: control, dairy, milking frequency, milking robot, production

Abbreviation key: AMS = automatic milking system, ICS = individual concentrates supplementation, MF = milking frequency, MR = milking robot, MU = milking, SF = self feeder, SU = selection unit

1. Introduction

The milking robot (MR) concept was developed in two directions: I) Replacing the manual work of cluster attachment in the conventional milking parlour (Sonck, 1995). II) Replacing the milking parlour itself (Schön et al., 1992; Devir et al., 1993a). The first relieves the farmer of substantial
work associated with the milking process but not of the necessity of his constant presence at every milking. The second direction aims to release the dairy farmer from the milking process all together. The advantage of the second approach is obvious and most of the research and development effort in MR is devoted to it.

The future prospects affected by MR are beyond that of release from constant milking activity every day. The MR system can operate as a milking device that fulfils the traditional demand of constant milking frequencies (MF) for all cows in the herd, or that adjusts the number of milkings to the needs of each cow. Both possibilities can be implemented together with the preferred individual concentrates supplementation (ICS).

Current technologies, existing and under development, offer the dairy industry the possibility of new management strategies based on automatically controlled systems which adjust appropriately for the individual cow. Behavioural, reproduction and health performance data can be characterized for each cow. In integrating the MR technology, referred to as the individual production approach (Maltz and Metz, 1994), we can also analyze performance data such as milk yield, body weight and feed intake. These data can trigger the implementation of appropriate management decisions through expert systems (Grinspan et al., 1995). In this respect, the concept of MR is penetrating the dairy industry when the climate is favourable. It makes production control possible and increases efficiency by incorporating milking, concentrates allocation and cow traffic into the system’s management functions on an individual cow basis.

A dairy control and management system (DCMS) (Devir et al., 1993a) has to ensure that the milking and feeding capacity of the machines performs in a way that extracts the most efficient production from a given number of cows. This can be achieved by a combination of milking and feeding facilities. The DCMS concept can be implanted in dairies applying different management strategies in terms of number of milkings a day, or incorporating grazing. It opens the way for innovative management strategies and planning in the dairy industry that can be used in addition to current management practices (including grazing), or can replace them. We can then refer to the MR dairy as an automatic milking system (AMS) rather than an MR dairy.

In this paper we will deal with the AMS management strategy and control, concentrating on the implementation of the strategy in relation to system management functions, rather than components. The only DCMS dairy which has been tested to date was incorporated into the loose-house system dairy, with a small herd (Devir et al., 1994ab, 1995a,b). No field test combining MR with grazing has been reported up to the present day. This paper therefore gives more emphasize to the loose-housing system dairy than to the grazing system dairy. A full account is given of the system that includes the MR and self-feeders (SF). The SF are located in the milking unit (MU) and in selection units (SU). In addition to supplying feed concentrates, the SU acts as a "holding pen" for cows, which can then be diverted to the milking site, as the system decides (Devir et al., 1993b, 1995a,b). The first section of the paper will discuss the MR DCMS strategic considerations relating
to AMS management. Then the implementation of the AMS dairy farm strategy at the operational control level will be discussed. Finally, the management functions: milking frequency, concentrates allocation and cow traffic, will be discussed in detail.

2. Strategic planning for the AMS dairy farm

Integration of the AMS into the dairy requires adaptation of both management and facilities (Devir et al., 1993a). Dairies differ from one another in their management strategies (Fig. 1). To benefit from the AMS as a management tool, in addition to its use in routine milking activities, the farmer can draw up a plan for the operation of his dairy. The plan should match his needs as well as the facilities available. There are five main strategic considerations for planning: concentrates rationing, grazing (with or without indoor forage rationing), number of milkings as determined by herd size or milking frequency (MF), facilities and labour (mainly the farmers' involvement in strategy implementation) (Fig. 1).
2.1. Concentrates rationing.

Within the given constraints of financial conditions and the availability and quality of feed stuffs, decisions on the rationing of concentrates have to be taken according to the milking strategy implemented, especially if adopting the individual approach.

In the AMS dairy, management of concentrates rationing is derived from the planned approach: feeding groups, grazing or the individual approach. Fig. 2 shows the possible utilizations and locations of concentrates rationing using individual and group management approaches. SF can be allocated at either the milking parlour, the barn area (lying or feeding sectors), SU or MU or any possible combination. To increase the attractiveness of the MR site in the AMS dairy, concentrates should be allocated only at the MU or SU in order to attract cows to visit these sites (Devir et al., 1993b). Concentrates consumption is influenced by the restricted time available for the cows to use the facilities involved and by the availability of the cows to attend the SF sites. It is possible that cows with a high daily concentrates allocation may not consume the planned concentrates ration. Grazing, as well as mixed ration feeding, may limit flexibility in using ICS as a management tool to control production on an individual performance basis, because no
quantitative information regarding intake is available.

2.2. Grazing

Grazing narrows down the MF possibilities, because during grazing neither milking nor ICS can occur. However, a variety of possibilities exist even under these conditions. A milking frequency higher than twice daily is possible even when cows are grazing for 12-14 hours. The duration of grazing can be reduced in order to allow a MF higher than twice daily, with more equal milking intervals (Sonck, 1995; Bottema, 1992).

2.3. Herd size and milking frequency

The milking process itself, which includes cluster attachment, milking and cluster removal, is determined by the robots' technical quality and by the cows' milking merits. The timing for each cow in the herd is therefore more or less fixed, and without any other slow-down factors, the maximum number of milkings per day under a specific MF strategy is highly predetermined. Field tests and milking robot companies' reports (Rossing et al., 1994; Devir et al., 1995a,b) indicate that, given a free cow traffic routine and full occupation, MR capacity might achieve more than 130 for one MU per day (Devir et al., 1995). The combination of planned MF and herd size will determine the number of MUs needed. However, to avoid long queuing before milking, when using a free cow traffic routine, milking large groups in one MR site is not recommended. A possible solution may be to group big herds according to MF preference or production potential, and to milk on different MR sites on the farm.

2.4. Facilities

There are several ways of integrating the milking and feeding functions of the system, all of which are available on the open market or operate as prototypes (Fig. 3).

1) One MR operating in one MU that also serves as a SF. In this case its milking activity ceases when it acts as a feeding station only. To avoid this, feeding can be restricted purely to milking time. However, this severely curtails the flexibility of ICS. If the MU should serve as a plain SF in addition to its milking capacity, without restricting the number of milkings, more MUs are needed.

2) One MR operating in more than one MU (Sonck and Donkers, 1995). In this case the MU can act as a SF or MU as required. In addition the MU serves as a "holding pen" for cows waiting for the robot. This reduces the number of expensive robots needed to perform a certain number of milkings, with fewer constraints on the milking-feeding integrated system.
performance than in the previous case.

3) Using several SFs that are connected to the MU by means of controlled gates so that cows can be diverted into the MU as decided (Swierstra and Smits, 1989; Devir et al., 1993a). In this way the SFs serve as SUs in addition to their self-feeding function. Cows that should be milked can be "trapped" and sent to the MU when it becomes vacant, or diverted back to the herd if they are not scheduled for milking. This option differs from the other two in that only cows that have to be milked reach the MU.

4) A combination of 2 and 3.

Fig. 3. Four possible ways of integrating the selection unit, self feeder and milking unit in the

2.5. Labour: the farmers' involvement in strategy implementation

The strategic decision regarding MF also includes the farmer's personal involvement in its implementation. Almost any AMS strategy (Fig. 1) can be implemented in almost any dairy. However, since automation depends on facilities for proper performance, any system handicap has to be replaced by manual work. In addition, a certain routine might not work with some cows because of their inability to adapt (Devir et al., 1995a). If this cannot be solved by a system
operational adjustment (Ketelaar-De Lauwere, 1992; Livshin et al., 1995), only the physical labour of bringing a certain cow to a certain place will fulfill the demands of the system. It is probable that a certain strategy will be only partially implemented and then the farmer has to decide on the amount of labour he wishes to invest in order to improve its operation (Devir et al., 1995a,b). It was reported by Devir et al., (1995a,b) that under certain circumstances, based on cow voluntary visits to the AMS, milking can be done automatically two or three times daily. Grazing may call for a simple routine exit from, and re-entry to the barn, which will require the farmer's minimal personal involvement for proper execution. The decision is implemented within the AMS capacity limitations. With or without AMS, grazing requires daily attendance in directing and assembling the cows, both before and after it takes place.

The dairy farmer will decide how to implement the planned strategy according to his own aims, whether these are: full automation of the daily milking and feeding routine or increased production efficiency (on a herd or individual basis), or both. The degree of individuality and automation in the management functions in the system will depend on the way his dairy is operated (Fig 1). In the traditional way all the cows are brought for milking to the MR site and ICS is allocated in SF at the barn or milking parlour (Fig 2,3). In the semi-automatic controlled dairy, not all the functions of MF, ICS and cow-traffic are individually controlled and implemented in parallel. For example: I) allocating part or all of the concentrates in the mixed ration (Fig. 2). This reduces the flexibility of the production control which uses concentrates as a tool. II) Applying a MF strategy without the appropriate lay-out and cow traffic control to ensure the availability of cows at the MR site at the time they need to be milked. In this case the farmer has to become the dairy cow traffic supervisor. In the fully-automatic individually controlled dairy, all three system management functions are automatically controlled at the individual cow level. It should be emphasized that most of the possibilities described above have not yet been thoroughly investigated, or even tried out.

3. Strategy implementation and operational control

Expanding the scope of the AMS concept to include an individual management approach, in addition to the technical milking capacity, requires an integrated control system that combines machine and animal management routines. The system has to adapt itself, the cow has to adapt to the system, and the two have to respond to each other. In this respect the AMS performance has to be controlled by a decision-making process which complies with a milking-feeding management policy. The decisions are applied individually and must interact with the cows' capacity to respond to them. (Devir et al., 1993; Maltz and Metz, 1994). It is obvious that the control system has to make on-line decisions. In addition, it requires the capability of reviewing the decision until its execution, and the ability to change it if conditions change (Huirne, 1990).
An example of on-line decision-making, based on strategic planning as well as on-line information, is described in Fig. 4. A cow enters the SU at a time that fits her milking schedule but the MU is occupied. A decision is made that she should wait to be milked and meanwhile she should be allocated ICS. After the decision has been taken, a delay in the milking process (e.g. cluster attachment) occurs in the MU. A new estimate is made as to whether the new expected waiting time is still within an acceptable range. An acceptable range is a range which would not cause frustration in the cow because of too long a waiting time at the SU, or would not cause a slow-down in cow traffic in the AMS (Devir et al., 1995a). Then a new decision is made to continue holding the cow in the SU and to divert her into the MU when it becomes vacant. While she is waiting another cow, reaching her milking time, enters the second SU. The cows are assessed and a priority is established. In the described example the second cow receives a higher priority for milking than the first one. A new set of estimations has to be made for the first cow, in order to decide yet again whether to keep her in the SU to be milked after the new cow, or to release her back to the herd immediately.
Each time a revised decision is needed, on-line information is compiled to fit the strategic planning and estimation of the consequences on cow behaviour e.g. frustration due to an excessive waiting time before milking. Similar decisions have to be taken in the combination of one robot serving several milking stations without a SU (Fig. 3). In the case of a single MU that also serves as a feeding station the decision-making process is less flexible. Once the cow enters it and a decision is taken whether to milk or feed her, the next decision, (whether for this cow or for another cow which enters the SU in the meantime) will be made only after the first one has been executed. In other words the "revising decision" function is absent. The flexibility of such a system can be increased by an identification system that selects cows before entering the MU, and identifies cows that make an attempt to enter it when it is occupied (Fig. 3). Then the "revising decision" function can be incorporated into the system to provide greater flexibility.

During this process a variety of on-line and pre-determined parameters have to be considered as well. The most important include: the specific MF of the cow, the herd and cows' SU visiting behaviour, the expected duration of milking, the amount of concentrates that can be allocated in the SU and MU.

4. Integrating milking, feeding and cow traffic functions

System performance control should aim to utilize the full milk production potential of each cow in the herd by optimal utilization of the technological facilities. Achieving this goal depends on reaching the optimal balance between the capability of the AMS to regulate MF and ICS, and the production capacity of the cows, which has several performance-related components. The optimal balance between: a) the operation and control of the technological components, and b) the animal performance capacity, and the ability to affect it in a given dairy environment, is one of the challenges for research and management. However, there are several technologies for animal performance-related characterizations that will play a role in the desired balance. These can be characterized by the relations between MF and concentrates allocation (the technology-oriented components) and milk production and body reserves balance (the animal-oriented components).

Our approach to performance control is based on the fact that lactation is a dynamic process, during which management decisions, if executed at the right time for the right cows, can affect it in a predictable and favourable manner (Spahr et al., 1993; Maltz et al. 1992). All cows demonstrate performance characteristics that are similar in their general pattern throughout lactation. However, their performance differs vastly from one to another in terms of magnitude and mutual relations. By applying the individual approach of AMS, we can act on all the performance variables. In order to control them we need: 1) frequent and reliable performance data (health, reproduction, behaviour and production), 2) to analyze the meaning of these in relation to available management changes, 3) to estimate the effect of a management change,
4) to make a management decision, 5) to analyze the effect of a management change in relation to expectations. All this has to be done on an individual daily basis (Maltz and Metz, 1994).

It is impossible to divide performance into separate controllable components. Affecting milk production has an effect on energy demands and on its complex relation with body reserves balance. However, methodologically we can describe separately control of milk production, food consumption and fattening, bearing in mind that they are closely related. We can thus also design integrated control responses to these relationships. Maltz and Metz (1994) describe the required data and possible ways of analyzing, making conclusions and timing the execution of management decisions in an AMS environment.

The AMS integrates three functions: milking, concentrates feeding and cow traffic. All functions can be manipulated in any preferred manner (Fig. 1), to affect performance. However, it is cow traffic that determines cow turnover through the facilities that execute the milking and feeding functions. Although technological and animal-related factors differ by nature, they are linked in the implementation of the integrated management functions in all of the above-mentioned combinations. Their linkage occurs at the strategic as well as the implementation level.

Milking and ICS functions can be performed at the same site or at different sites. They can be executed in parallel or separately (Fig. 2,3). Each of the possibilities has its advantages and disadvantages. However, since the principal function, (and the most costly), is that of milking, the main concern in planning system performance and control should be the efficient execution of the milking process, at the desired frequency.

### 4.1. Milking frequency

With conventional milking parlour husbandry, the predominant way to increase milk production (MP) is through nutrition. Another well-known method is by increasing MF. However, farmers limited by milking parlour routine have been unable to use it. With AMS, the possibility of using MF as a husbandry management tool to increase production (Bar-Peled et al., 1992; Hillerton and Winter, 1992; Remond et al., 1992) becomes a reality. Moreover, this can be done at the individual cow level. From preliminary short-term trials performed so far (Devir 1994; Devir et al., 1993a, 1994, 1995a,b), it seems that cows can adjust, at least to some extent, to unequal milking intervals.

When there is no grazing, the first decision is whether all the cows are to be milked at the same MF throughout lactation. If so, the next decision is what MF to apply (Fig. 5). If a non-uniform MF is to be applied, then a large number of possibilities is available. This ranges from strategies of uniform overall decisions, such as: all cows are milked at the same MF after calving, and any reduction in MF is production or time-dependent, to the strategy of an individual approach, where each cow is milked at a frequency that responds to performance in order to control it (Fig. 5). This function is executed after decisions have been taken at two levels: 1) The strategic level which
Management planning and implementation determines the guidelines and specification upon which the control has to perform. 2) The on-line level which implements the single milking dictated by the strategic decision, under the conditions and circumstances specified for its implementation.

As described above, the maximal number of milkings a day is predetermined. On the one hand, we may aim to reach maximal production by applying an individual milking regime to each cow. On the other hand we are interested in milking as many cows as possible by the AMS. Thus, applying a high MF to increase production is limited by: a) the maximal daily milkings the system is capable of, and b) the number of cows the AMS has to serve in the dairy. In this respect, when determining an individual milking regime for a certain cow, the control system has to aim to reach the highest production from an individual cow with the lowest number of milkings. The works by Bar Peled et al. (1992), show a carry-over effect throughout lactation after a short period of high MF starting at calving. In describing the role of the mammary cisternal capacity in the relation between MF and milk production, Knight et al. (1995a, 1995b) indicate a possible direction for the achievement of this aim.

For example: we can apply a high MF for a short period after calving, but only for the time needed to achieve the carry-over effect that will last after MF is gradually reduced to a minimal value. This means that at any given time a different MF will be applied to each different cow in

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Fig. 5. The possibilities of applying uniform and non-uniform milking frequency under individual and herd management approaches.
the herd, because each cow a) is at a different stage of strategy execution, and b) has a different response capacity to high MF. Executing a strategy like this for every cow in the herd requires a rather complicated control system that has to integrate the technology-related components, such as the availability of each cow for milking at the time that fits her MF on any given day, and animal-related components, such as when should MF be reduced and for which cow?

Responding to the animal related component, we have to implant criteria on milk production into the control system as a threshold for changing MF. This means frequent analysis of milk production data, the search for the threshold, and the implementation of a reduction in MF once it occurs. It is complicated enough when the only performance variable that the AMS has to respond to is milk production. However, we know that a forced increase in milk production at the beginning of lactation is not necessarily supported by the cows' ability to increase food intake (actually it rarely does). In this case the cow might rely heavily on body reserves to an undesired extent, which will in turn cause a lactation curve collapse, and increase vulnerability to disease and reproduction disorders. Thus, the control system has to respond to body weight (BW) changes as an indication of body reserves balance and food intake (Maltz and Metz, 1994).

4.2. Concentrates allocation

Increasing milk production by the use of high MF has to take into account the resultant increase in energy demands. This can be achieved by a proper ICS strategy. The ICS function has two aspects. The first is to attract the cows to the MU or SU in a desired sequence (Pirkelmann, 1992; Devir et al., 1993b). Livshin et al. (1995) demonstrated that SF operation can regulate the visiting behaviour of the cows to a desired sequence. Thus, the technology-related component is controlled by programming the SF to allocate the daily concentrates ration at intervals that fit all the possible MFs applied to members of the herd. The second aspect is the provision of the nutritional supplements that are not fed via the feed bunk. In addition to this, the concentrates are usually the expensive component of the ration and have to be treated accordingly. The control of concentrates feeding in the system must therefore respond to the milking function (high MF requires appropriate concentrates allocation as an attractant), to animal demands (according to performance and forage intake and quality) and to financial constraints (availability and cost of concentrates as well as forages). In other words, providing concentrates in amounts to satisfy attraction criteria could exceed nutritional requirements and would thus be uneconomic. The possible methods of feeding concentrates in the AMS dairy has to be decided first at the strategic level. The ICS planning strategy can be implemented in various ways, as presented in Fig. 2,3. Any method of allocating ICS has it advantages and disadvantages. For example: feeding all the concentrates through the SF, thereby risking insufficient consumption for cows on high rations, or feeding some of it as a mixture in the bunk thereby risking the disappointment of cows on low
rations (Ketelaar-de Lauwere and Benders, 1994).

Our success depends on: a) the systems' ability to satisfy the cow's energy demands, and b) the cow's capacity to consume the concentrates. Both functions depend on our ability to control the cow's behaviour pattern so as to ensure adequate diurnal presence in the milking and feeding facilities. Appropriate control of cow traffic can satisfy this demand.

4.3. Cow traffic

The availability of the cow at the MU or SU within predetermined intervals is needed to achieve fully-automated implementation of the planned MF and ICS. If hardware and software operate properly, then the number of daily milkings of any robot is determined by the time it takes for cows to replace each other in the MU for milking purposes (Devir et al., 1993b, 1995a,b). This also includes the time when there are no cows "queueing up" for milking. The cows can be driven to the AMS by the farmer. Cow traffic through the MU without such manual work can be achieved by: I) technical means or a suitable lay-out (Ipema, 1995), II) ICS attracting cows to the MU (Ketelaar-de lauwere, 1992) and III) any combination of I and II (Pirkelmann, 1992; Devir et al., 1993b).

Fig. 6 presents the possible combinations of farmer-driven, forced and voluntary cow traffic. The cow traffic combinations are presented in relation to the four possible AMS barn modules: SU, MU, the barn area (lying and feeding area) and grazing. It appears that the combination of SF in a SU may yield optimal results for AMS efficiency (Devir et al., 1995),(Fig. 3). In this way we can "trap" cows and form a "queue" for diversion to the milking station even when it is occupied. A set of controlled gates can divert cows in the preferred direction.

Considerable work has been devoted to cow traffic to the AMS, and within the AMS facilities under these conditions (Ketelaar- De Lauwere, 1992; Metz at al., 1993; Devir et al., 1993b,1995,a,b). There were some disadvantages for MR efficiency in these attempts to control cow traffic, e.g. the fact that all of them were carried out in conventional barns that were not initially designed as MR operating dairies. The second is that with the exception of Devir et al. (1993) and Devir et al. (1995a,b), the experiments were based on twice-daily milking for all cows. The control over such automated cow traffic has to absorb on-line and off-line information for successful execution of the decision-making process. Examples of such information which should be included in the control system are: 1) the duration of every milking of each cow (estimated within a narrow range), 2) the time between successive milkings, 3) the idle time the cow spends between the SU, MU and the controlled gates (Fig. 3), 4) the decision on whether to keep the cow for milking (fig. 4) and 5) the amount of concentrates to be allocated during her waiting time for milking.
Fig. 6. Possible cow traffic path and its characteristics (farmer driven, forced by technical means or lay-out, voluntary) for the four main sub-structures of the AMS dairy.

5. Conclusions

MR can be integrated into any type of existing dairy. However, utilization of the AMS differs from one dairy to another. The way the farmer uses the AMS depends on his needs, available facilities and management priorities. Integration of the MR can be from the lowest level only (as a replacement for the milker in the milking parlour) up to the fully-automatic control of individual cow production and daily routine, with minimal involvement of the farmer. In short, the AMS can be regarded as a system that vastly increases dairy management flexibility. Only a few field tests using MR have been reported to date. However, those that have been performed proved that fully-individual control of AMS routine is more than possible. No field test involving grazing has yet been reported, but some commercial dairies using MR already integrate grazing into their systems. More field tests are needed to assess the various prospects and efficiency of the integration of the MR into the dairy farm.
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Chapter 8

General discussion and conclusions

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1. Introduction

The research described in this thesis was directed towards the technical and managerial integration of the milking robot into the dairy farm. Attention was focused on the implementation of an individual production and behaviour-based strategy, using cow traffic, milking frequency and individual concentrates allocation as the control tools. When the system runs smoothly it can result in both better quality of life for the herdsman, and an improvement in production efficiency, system capacity and cow welfare.

The integration of the milking robot into the dairy farm requires a change in management concepts and tools. A new management concept for the AMS was therefore formulated (Chapter 2). Guidelines for building a dairy control and management system (DCMS) were derived from this new AMS concept. The heart of the DCMS concept is the approach to the cow as an individual. A set of parameters was introduced which represents the individual cow’s production and behaviour pattern in addition to herd and AMS capacity characteristics. A first prototype of the DCMS and a set of decision making parameters were tested in a short feasibility test (Chapter 3). The feasibility test showed that automatic on-line control of milking and concentrates allocation based on an individual approach was possible. A set of rules was formulated from the results of the feasibility experiment and programmed into an expert-system as a component of the DCMS.

Then a second field test, was conducted, when cow traffic, milking and concentrates allocation were controlled by the DCMS (Chapter 4). The aim was to study cow behaviour and DCMS performance under maximal AMS capacity circumstances. Finally, a long term field test (7 months) was conducted based on the knowledge acquired during the first two field tests. During this test the DCMS controlled milkings, cow traffic and concentrates allocation. The aim was to test the performance of two groups of cows using two different AMS management approaches: I) A control group consisting of cows milked three times daily throughout the experiment, and allocated concentrates according to normal Dutch practice. II) An experimental group in which the cows were milked at a variable high milking frequency, based on a daily individual evaluation of the cows’ fat corrected milk yield, body weight and feed intake. The aim of the experiment was to assign an individual milking and concentrates allocation strategy to the two groups, in order to increase production efficiency and achieve a fully-automatic DCMS controlled daily routine (Chapter 5). Production performance aspects of the experimental AMS groups were analyzed and compared both within the AMS cows groups, and to those of cows milked in a traditional milking parlour, under similar nutritional conditions to those of the fixed milking frequency AMS cows (Chapter 6). Following on from this comparison, different practical aspects of planning and implementing an AMS strategy are discussed in detail (Chapter 7).

In this general discussion the experience obtained during the development and testing of the
DCMS is reviewed and discussed in the context of its technical and managerial integration into the dairy farm.

2. Scope and definitions

An automatic milking system is more than a robot for attaching teat cups. The milking robot can be used to avoid the manual work of attaching the teat cup or as an alternative to the milking parlour itself. In both cases a reduction in labour is expected (Sonck, 1995).

But the opportunities offered by the milking robot can be much greater. From the farmer's point of view, the AMS should minimize his involvement in the process of milking, concentrates allocation and cow traffic, and should improve his quality of life. From the cow's point of view, the AMS may increase production (milk yield, milk fat and protein) by a higher milking frequency, supported by an appropriate individual concentrates allocation which in turn prevents negative effects on health and reproduction during the lactation period. Cows which produce large amounts of milk at long intervals appear to lie down less during the last few hours before milking because of greater pressure in the udder. If milking frequency is increased it is to be expected that this inconvenience would cease and cow welfare would improve (Kuipers and Scheppingen 1992; Ipema et al., 1988).

Industry has invested much effort over the last 10 years in the introduction of the milking robot to the dairy farm (Bottema, 1992; Marchal et al., 1992; Dück, 1992; Rossing et al., 1994). To date, more than 25 milking robots have already been sold by Prolion and Lely industries (Rossing et al., 1994). However, the integration of the milking robot into the dairy farm is still at an early stage. There are no reports describing the effects on production, reproduction, health and behaviour when a milking robot is integrated into the dairy. The DCMS concept and tools for the fully-automatic milking robot dairy have not yet been tested or validated over a long period by any milking robot company or research institute.

To fill this gap, and to assess the real potential of the milking robot (apart from teat cup attachment), a DCMS for a loose housing dairy using a milking robot was developed and tested in this research thesis. The DCMS which was developed and tested offers a management solution, both conceptual and operational, for the medium scale loose housing dairy (up to 80 cows), where no grazing management is applied. The experience gained from the field tests might also contribute to the integrating of the milking robot into larger dairies with or without grazing management.

3. The DCMS

New technologies, both existing and under development, enable the acquisition and analysis
of performance data for each cow. Using decision support systems, management decisions can be taken and implemented according to performance. Cow management usually refers to data acquired not only at the milking parlour, or in our case in the milking unit (Mottram, 1992). Today, the modern dairy farm uses a dairy management system as a support system for the herdsman in his overall management control of the dairy. More information such as body weight, cow movement within the barn, and forage intake can be collected automatically during the day. Such an amount of data can be analyzed only by a computer. In the AMS dairy each cow can be milked and fed according to her production profile and behaviour pattern at any time during the day. Because the farmer cannot be present each time a milking or concentrates decision is needed, a new generation of dairy control and management systems, the DCMS, takes over (Chapter 2).

In the fully-integrated controlled AMS dairy, the milking, concentrates allocation and cow traffic are automatically processed. The DCMS acquires data on a daily basis, analyzes it, and adapts the milking frequency and concentrates strategy for each cow according to her performance and the system's limitation. At the on-line level, each time a cow enters the milking unit or a selection unit before the milking unit, the DCMS makes the milking and concentrates allocation decision. The short-term and long-term history of what has happened to the cows is stored in individual cow records in the DCMS. The DCMS is defined as a self-learning decision support system. The milking and concentrates strategies are assigned to cows as far as they can adapt within their physiological and behaviourial limits, and within the limitations of the system. In this way the cows are not forced to adapt to the planned strategy but on the contrary, the system adapts itself to the cows.

Because of technical limitations in our system, the flow of data from the various sensors to the DCMS, and the flow of instructions from the DCMS to the controllers (gates and feeders), were channelled via both a Vax and a PDP computer (Devir et al., 1995). This meant that a dynamic revision of decision on milking and concentrates allocation was not possible while the cows were in the milking unit or in the selection unit (Chapters 5,7). This inability of the system to change a decision while the cow was in the selection unit, led in case of concentrates allocation, to a lower actual supplementation than was planned (Chapters 3,4,5). This low supplementation rate occurred despite the fact that there was enough time to allocate all planned concentrates. In an attempt to overcome the problem, the planned allocation of concentrates at the selection unit and milking unit was pre-calculated daily, based on individual predicted milkings and visits to the AMS (Chapter 3,4). However, cows which did not visit the AMS as expected were not always supplemented as planned.

In the case of the milking decision, an estimate was made when the cow entered the selection unit of how long she was likely to wait until milking. The absence of direct gate control based on on-line information led sometimes to wrong DCMS decisions. These wrong decisions were based on a prediction of events instead of on a continuous flow of information. In some cases cows were
sent back to the herd because of faulty information on too long an expected waiting time, or they were kept for milking longer than was necessary. For practical purposes, the DCMS should be installed on a desktop computer at the dairy. The DCMS should then acquire all information directly and should have direct control over all the controllers in the dairy, i.e. the milking robot, self-feeders, selection units and gates.

4. The integration of the milking robot in the dairy farm

4.1. The role of the selection unit in the AMS farm

To benefit from the high investment in the milking robot, the system should be as busy as possible during the day (excluding short periods for the cleaning and maintenance routine). Cow visits which do not deserve milking at the milking unit, and overload the AMS, should be avoided. Using the milking unit only as a concentrates self-feeder is in-efficient (Chapter 3). Implementation of an individual milking frequency and concentrates allocation strategy requires control. Thus using a selection unit before the milking unit is the preferred solution, to eliminate idle usage of the milking unit on the one hand, and to enable individual control of the milking frequency and concentrates allocation on the other. Selection units are relatively cheap devices. The time cows have to wait before milking can be utilized to allocate concentrates. The time cows spend at the selection unit and the milking unit is enough to allocate high volumes of concentrates (up to 18 kg/day).

The use of selection unit for cow traffic within the AMS dairy, with no human intervention, causes idle time within the AMS section. The idle time consists of the exit time from the selection or milking units or the passage duration between the various AMS facilities. The time taken for cows to exit the selection unit towards the milking unit is less than the time taken for their return to the herd. The use of a cow-friendly pusher to accelerate the cow in leaving the selection unit and milking unit can shorten the exit time. The cows should not wait too long at the selection unit. This could frustrate them, affect their visiting pattern negatively and slow down cow traffic within the AMS section (Chapter 4,5). The cow traffic bottle-neck within the AMS described in the field tests was the milking unit occupation time. The use of at least two milking stalls as a minimum is therefore recommended. The ratio of two selection unit to one milking unit proved preferable.

4.2. Attracting cows to the selection unit

In the fully-automatic dairy cows should report voluntarily to the selection unit. Cows can be attracted to the selection unit either by methods of reward or pathway configuration. In the free
cow traffic routine (chapter 4) cows attended for milking voluntarily less than in restricted one-way traffic (Chapter 5). In both pathway configurations (Chapters 4, 5) milking the cows three times a day, based on voluntary visits to a selection unit, is possible. In the one-way restricted pathway described in Chapter 5, cows can be milked at least 4 times a day without needing to be brought to the selection unit by the herdsman. Higher milking frequency might involve some extra labour. The farmer must decide whether the returns from a high-yielding cow, (which might be recommended by the DCMS for milking 5 or 6 times a day) are worth the extra labour needed to bring cows to the milking unit once in a while.

Rewarding cows individually by milking and concentrates at the right time is another successful way of achieving smooth cow traffic flow in the AMS. It appears that the cow memory of what happened to her during her last visit to the selection unit has the most significant effect on her visiting pattern to the selection unit (Chapters 4, 5). The amount of concentrates allocated also had a significant effect on the cow’s subsequent visits to the selection unit. When cows were consistently rewarded by milking or concentrates, or both, only once during each time window, they adapted their visiting patterns to at least one visit during each time window (Chapter 5). Cows which experienced un-justified un-rewarded visits came back shortly after their last visit. All the above leads to the conclusion that cow visits to the selection unit can be regulated either by pathway configuration, or by an individual consistent milking and concentrates reward system. Both can be used as a practical management routine in the AMS dairy.

5. Some more broad perspectives

Dairies differ from one another in their management strategies. To benefit from the advantages of the milking robot in his dairy, other than freedom from routine milking activities, each farmer should drawn up his own operational plan (Chapter 7). Guidelines for planning the fully-integrated DCMS environment are influenced by the system performance, cow performance and the interaction between the two.

There are several ways of integrating the milking and feeding functions of the system, all of which are available on the market or operate as prototypes. Two concepts dominate the milking robot market these days. The first is a single milking robot serving a single milking unit. In the second concept, one milking robot might serve more than one milking unit. Given that the minimum recommended number of milking units is two, the first concept means purchasing two milking robots. However, there will inevitably be situations where events occur that prevent or interfere with the normal process of automatic milking. These may be component failures, or cow-induced disturbance or rare external events such as lighting (Street et al., 1994). The use of only a single milking robot with two, three or four milking units might be a cheaper solution, but it makes the AMS more vulnerable. Because the milking frequency and concentrates allocation
proved to be significantly effected locally by AMS failures, in the course of time such failures might negatively affect the cows' production.

All the commercial milking robots offer the possibility of concentrates allocation during milking. However, the results of the field tests do not support the recommendation of allocating large amounts of concentrates only at the milking unit. This is further supported by the fact that not all the allocation at the milking unit was consumed during milking (Chapter 5).

The results of the field test indicate that in an AMS where there is always a cow available for milking, the maximal theoretical capacity of two milking units can exceed 360 milkings a day. However, the experience described in this thesis shows that reaching this maximum is not possible. The cows do not attend the selection unit at equally frequent intervals over the whole day. There will always be sick cows, cows in oestrus, or cows at the beginning of lactation which do not adapt to the AMS routine. Other disturbances such as system maintenance or system failure might also decrease the number of daily milkings. To achieve maximum AMS efficiency with cow voluntary visits to the selection unit, a herd size of up to 80 cows, which are milked 3 to 5 times a day, is recommended. If the AMS routine is applied to large herds, such herds should be divided into sub-groups of 40 to 80 cows, depending on the planned milking frequency and the ratio of milking robots to milking units.

The current milking robots developed in Europe are oriented to herds in the loose housing dairy when non-grazing management is applied. Under grazing management, full automation and control of both milking and feeding is restricted. However, the farmer can still benefit from an AMS under a management strategy which integrates grazing. The cows can be milked twice to three times daily after grazing at the pasture for 8 hours. Mean milking duration is estimated as about 6 to 8 min (Chapter 5). By using two milking units (which are recommended as a minimum, see above) theoretically, up to 240 milkings might still be performed in 16 hours.

If no grazing management is applied, then the farmers' flexibility in utilizing the milking robot is much greater. Controlling the concentrates allocation calculated according to the individual cow's body weight, milk production and feed intake, is possible whether or not the milking strategy is based on fixed or individual variable milking frequency. When a fixed milking frequency is applied, then the AMS can be regarded as a semi-automatically-controlled system. The milking process and concentrates allocation can be fully automated when it is based on cow voluntary visits to the milking robot site. Even large amounts of daily concentrates can be allocated using only the selection unit and the milking unit as supplementation sites.

However, to benefit fully from the AMS, each cow should be milked at her "own" milking frequency, based on her production and behaviour profile. The DCMS described in this thesis confirms that individually planned milking frequency and concentrates allocation can both be applied in a practical management procedure in the dairy.
6. Further research

The AMS configuration which is described in this thesis is oriented to the fully automatic loose housing dairy. There are many possible combinations for integrating the milking robot into the dairy farm. Observation in existing commercial milking robot dairies would expand our knowledge of these possibilities.

Long term field tests are needed for two types of management: those which comply with grazing management procedures and those in which cows are milked twice or three times throughout lactation. Field tests involving fully integrated AMS systems should trace the short-term as well as the long-term effect of AMS management on cow performance and welfare. In the short term, research should evaluate the effects on cow performance of such factors as mastitis, lameness, metabolic disorders and reproduction. Other effects that need careful observation are the effect of milking robot teat cup attachment time on the milk yield and the effect of unequal milking intervals on net machine milking time. This thesis has reported that high milking frequency cows have a longer lactation period. It has also concluded that not all cows would adapt to the AMS environment, and that some would have to be culled from the herd. The economic consequences of a longer lactation period and a higher rate of culling cows from the herd therefore need to be analyzed. Cows with a high milking frequency tend to maintain high milk production even after a reduction in milking frequency (Bar-Peled et al., 1992). This effect has to be checked during more than one lactation period in a large number of cows.

The data acquired from field tests should be compiled into an expert-system that can evaluate the cows' behaviour according to what happened to them. Such a system would adapt to the cows more appropriately and effectively.

Some of the methods involved in cow traffic flow such as the use of mechanical pushers at the selection unit exit, or directed one-way traffic between the lying and the feeding areas in the AMS dairy, may not be popular because of a potentially negative impact on cow welfare. Tests are needed on the interaction between the cows, the AMS pushers and one-way directed cow traffic.

This thesis does not deal with application of the DCMS to large herds. However, the results indicate that applying DCMS to herds of more than 80 cows might be a practical management procedure. To evaluate this assumption, milking robots should be installed and tested with a large herd for a long period.

The AMS is a complex system from both the technological and managerial point of view. There is a need to enhance management skills in dairy operation (Harsh et al., 1992). Such a technology will become a part of the dairy routine only if the technology can be packaged as learner-and-user friendly (Spahr, 1993). The DCMS advises the farmer on each cow's individual milking frequency and concentrates allocation, but the farmer is free to change the decisions made by the DCMS. That is why a friendly human interface which allows access to individual data (Devir and Metz,
1994) and the ability to change any DCMS decision threshold is needed.

Main Conclusions
- Automatic control of cow visit to the selection unit enables implementation of an individual milking frequency and concentrates allocation strategy, and can be used as a management practice in the dairy.
- One desk-top computer, directly linked to all controllers in the dairy, should control the milking and concentrates allocation.
- A combination of selection and milking units is needed both to achieve full control of high milking frequency and concentrates allocation and to maximize the capacity of the automatic milking system. The use of at least two milking units as a minimum and a ratio of two selection units to one milking unit is recommended to maximize the benefit from the automatic milking system.
- There is enough time to allocate large amounts of daily concentrates at the automatic milking system only. Additional concentrates self-feeders in the barn area are therefore unnecessary. The decision on concentrates allocation should be made on-line and dynamically adjusted if necessary, while the cow is still in the selection or milking unit. The use of pre-determined portions resulted in incomplete allocation of the daily planned concentrates.
- The cows' visiting pattern to the selection unit can be regulated by either pathway configuration or the reward of individual milking and concentrates. Cows adapt to the voluntary milking and concentrates allocation routine of the automatic milking system within 10 days after calving.
  Cows are most influenced by what happened to them during their last visit to the selection unit, with respect to their rewards, rather than by their daily milking frequency or parity. The reward of concentrates plays an important role in regulating cow visits to the milking robot site. Cows which deserve milking and are unjustifiably unrewarded (i.e. rejected) tend to visit the automatic milking system within a short time of their last visit. After entering the selection unit cows prefer to go to the milking unit rather than to the herd.
- When cows visit the selection unit voluntarily, a milking frequency of 4 times a day does not require any further involvement in bringing cows to the unit. Using a one way cow-traffic routine enables a high milking frequency of more than 4 times a day with relatively low farmer involvement.
- There will always be a small number of cows for the farmer to bring to the milking unit. The farmer will use his herd visiting profile to choose his preferred management strategy: a combination of daily milking frequency, the total number of milkings per day and the amount of physical labour necessary to bring some cows to the selection unit.
- Short-term system failures have only a short term negative effect on cow behaviour and
production performance.

- When cows which are milked and fed concentrates according to their performance are compared to cows which are being milked at a fixed milking frequency and fed concentrates according to Dutch standard practice, the former produce more 4% fat corrected milk per one unit of body weight. These cows also tend to have longer lactation and better reproductive performance.

References


Summary

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1. Introduction

The research and development described in this thesis was directed toward the design and validation of control and management concepts and tools for the milking robot dairy farm. The aim was to assign an individual milking frequency and concentrates supplementation regime to each dairy cow in a loose housing system, based on the cows' voluntary visits to the milking robot site.

The concept was characterized by building a dairy control and management system for the milking robot farm. Then a series of three field tests was conducted to validate the automatic milking system management concept, and the tools for its implementation.

2. Automatic milking system management concept and tools

Integration of the milking robot into the dairy farm does not only free the farmer from the physical labour of milking. From his own point of view, an automatic milking system should minimize the farmer's involvement in the milking, concentrates allocation and cow traffic process both to save time and energy and to improve his quality of life. From the commercial point of view, the automatic milking system increases production efficiency by raising milking frequency, supported by appropriate individual concentrates allocation. Because each cow can be milked and fed individually according to her behaviour and production performance, cow welfare is also expected to improve.

A dairy control and management system was designed, to handle the enormous amount of data acquired and processed in the modern dairy, and to avoid the necessity of the farmer's involvement in every individual milking and concentrates decisions. The dairy control and management system provides information on the cows' individual production performance and behaviourial pattern which is then evaluated to calculate the individual concentrates supplementation and milking frequency for the following day. Then the dairy control and management system implements the regime for each cow by automatically controlling the daily concentrates supplementation feeding and milking routine based on the cows' voluntary attendance at the milking robot site.

3. The validation of the dairy control and management system

In all the field tests conducted a milking unit equipped with a "Prolion" milking robot and a concentrates self-feeder was available for 24 hours a day. The cow-shed, a loose housing system, was divided into two main sections: 1) The lying and feeding areas. The passage between the areas was free (chapter 3,4) or restricted to one-way traffic, from the feeding to the lying area (chapter
The automatic milking system section. This comprises one or two selection units and a milking unit. Cows voluntarily attend a selection unit which is a concentrates self-feeder stall with controlled entrance and exit gates. Following the dairy control and management system decision, cows are supplemented concentrates and diverted either to the milking unit or to the lying or feeding area. Concentrates can be allocated only in the milking or the selection units. Cows were milked from twice a day (chapter 3), to 3 to 5 times a day throughout the experiment (chapter 4) or at a variable milking frequency, from 2 to 6 times a day (chapter 5,6).

The object of the first field test was to validate the use of the individual decision making parameters for both the on-line milking and concentrates decisions and to evaluate the short-term performance of the fully-automatic milking and concentrates supply routine in the dairy farm. During the last eleven days, the milking robot was available for milking for 24 hours a day. A set of variables and mathematical equations describing the visiting pattern and concentrates supplementation was processed. It proved possible to maintain an automatically-controlled milking and concentrates supplementation on a daily basis. The selection unit occupation time, together with the number of visits, proved a good performance measure of the system capacity performance. The use of a selection unit enabled control of cow traffic and concentrates allocation, but slowed down the traffic between the selection and milking units by a period of up to 5 minutes passage time. The results indicated that cows might prefer the milking unit to the feeding area.

Based on the first field test, a longer automatic milking and feeding routine experiment, based on voluntary cow visits to the selection unit, was conducted. A herd of 29 cows was milked for 8 weeks. The aim was to milk cows with different individual milking frequencies and daily concentrates allocations when they voluntarily visited the automatic milking system under maximal capacity conditions. Milking frequency varied between 2 and 5 times a day. If a cow visited the selection unit too often she was diverted to the lying area. One hour after milking all cows were diverted to the feeding area. In all other non-milking visits the cows could choose where to go after leaving the selection unit. Voluntary milking visits were above 90% of all milkings. However, the cows' visiting pattern (free passage between the lying and feeding areas) was sufficient to achieve a daily milking frequency of 4 times a day. The herd's daily visits were divided equally over the day. The interval between successive visits to the selection unit was affected most by what happened to the cow during her last visit. The relatively shortest intervals were found after unrewarded milking visits, mainly visits in which less than 0.5 kg of concentrates were allocated. Heifers visited the selection unit more frequently than cows.

Following on from previous experiments, an automatic control of a milking and concentrates supplementation routine was applied to a herd of 24 cows for 7 months. Two management concepts were tested: I) A fixed milking frequency of three times a day throughout the experiment and a weekly concentrates evaluation according to the usual Dutch practice II) A variable milking
frequency consisting of six times a day after calving, reducing to three times a day during the course of the experiment. The milking frequency and individual concentrates supplementation were evaluated daily by an expert-system based on performance criteria.

The management aim of the experiment was to milk and feed both groups as planned, by rewarding the cows with milking or concentrates allocation, or both, only once in each time window, of 4 hours duration throughout the day. The results showed that on average cows made at least one visit in 5.4 out of the six daily time windows. Cow assigned for milking 3, 4, 5 and 6 times daily were milked 106.9% (±18.6), 90.5% (±15.1), 93.9% (±17.3) and 79.9% (±15.0) respectively, as percentage of their planned frequency. Cows adapted to the automatic milking system routine within 10 days after calving, and voluntarily attended the selection unit for milking in 97% of all milkings. Daily concentrates consumption as a percentage of that planned was 97.8% (±21.97) and 106% (±18.88) during the first 10 days of lactation and during the remaining period of lactation respectively. There was enough time to allocate a high volume of concentrates (up to 18 kg/day) at the selection and milking units without slowing down cow traffic. Reproduction performance of the two groups was very similar. Fat-Protein corrected milk yield per unit of body weight, and 4% fat corrected milk production per unit of body weight for complete lactation, were significantly higher in the variable milking frequency group compared to the fixed milking frequency group.

Main Conclusions

- Automatic control of cow visits to the selection unit enables implementation of an individual milking frequency and concentrates allocation strategy, and can be used as a management practice in the dairy.
- One desk-top computer, directly linked to all controllers in the dairy, should control the milking and concentrates allocation.
- A combination of selection and milking units is needed both to achieve full control of high milking frequency and concentrates allocation and to maximize the capacity of the automatic milking system.
  The use of at least two milking units as a minimum and a ratio of two selection units to one milking unit is recommended to maximize the benefit from the automatic milking system.
- There is enough time to allocate large amounts of daily concentrates at the automatic milking system only. Additional concentrates self-feeders in the barn area are therefore unnecessary. The decision on concentrates allocation should be made on-line and dynamically adjusted if necessary, while the cow is still in the selection or milking unit. The use of pre-determined portions resulted in incomplete allocation of the daily planned concentrates.
- The cows' visiting pattern to the selection unit can be regulated by either pathway configuration or the reward of individual milking and concentrates. Cows adapt to the
voluntary milking and concentrates allocation routine of the automatic milking system within 10 days after calving.

Cows are most influenced by what happened to them during their last visit to the selection unit, with respect to their rewards, rather than by their daily milking frequency or parity. The reward of concentrates plays an important role in regulating cow visits to the milking robot site. Cows which deserve milking and are unjustifiably unrewarded (i.e. rejected) tend to visit the automatic milking system within a short time of their last visit. After entering the selection unit cows prefer to go to the milking unit rather than to the herd.

- When cows visit the selection unit voluntarily a milking frequency of 4 times a day does not require any further involvement in bringing cows to the unit. Using a one way cow-traffic routine enables a high milking frequency of more than 4 times a day with relatively low farmer involvement.

- There will always be a small number of cows for the farmer to bring to the milking unit. The farmer will use his herd visiting profile to choose his preferred management strategy: a combination of daily milking frequency, the total number of milkings per day and the amount of physical labour necessary to bring some cows to the selection unit.

- Short-term system failures have only a short term negative effect on cow behaviour and production performance.

- When cows which are milked and fed concentrates according to their performance are compared to cows which are being milked at a fixed milking frequency and fed concentrates according to Dutch standard practice, the former produce more 4% fat corrected milk per one unit of body weight. These cows also tend to have longer lactation and better reproductive performance.
Het besturings-en managementsysteem voor het melkveebedrijf met een melkrobot

Samenvatting

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1. Inleiding

Het in dit proefschrift beschreven onderzoek betreft het ontwerp en de beoordeling van regel- en managementconcepten en hulpmiddelen voor het gebruik van een melkrobot op het melkveebedrijf. Daarbij was het doel voor elke koe in een loopstal een individuele melkfrequentie en individuele bijvoedering met krachtvoer te bepalen, gebaseerd op vrijwillige bezoeken van de koe aan de melkrobot.

Het onderzoekconcept wordt gekenmerkt door het opzetten van een regel- en managementsysteem voor het gebruik van een melkrobot op een melkveebedrijf. Een reeks van drie praktijkproeven werd uitgevoerd ter beoordeling van het concept en de hulpmiddelen die bij het automatisch melken worden gebruikt.

2. Managementconcept voor automatische melksystemen en hulpmiddelen

De integratie van de melkrobot op het melkveebedrijf verlost de boer niet alleen van de fysieke arbeid tijdens het melken. Vanuit het gezichtspunt van de veehouder moet een automatisch melksysteem ook zijn overige bemoeienis bij het melken, de krachtvoerverstrekking en het koeverkeer tot het minimum beperken om tijd en energie te sparen en daardoor de werksituatie op het bedrijf te verbeteren. Vanuit het commerciële gezichtspunt gaat het bij een automatisch melksysteem om de stijging van de produktiviteit van de koeien doordat de melkfrequentie wordt verhoogd, wat nog wordt versterkt door een juiste verstrekking van krachtvoer op individuele basis. Omdat elke koe individueel kan worden gemolken en gevoerd, waarbij wordt uitgegaan van het getoonde gedragspatroon en het produktieniveau van het dier, wordt verwacht dat ook het welzijn van de koeien verbetert.

Er is een regel- en managementsysteem ontworpen om de enorme hoeveelheid gegevens die op een modern melkveebedrijf wordt verzameld en verwerkt, te kunnen beheren en ervoor te zorgen dat de boer zich niet hoeft bezig te houden met elke beslissing over het individueel melken en voeren.

Het regel- en managementsysteem voor melkvee verstrekt informatie over de melkproduktie en het bezoekpatroon van individuele koeien aan de melkrobot. Deze informatie wordt vervolgens uitgewerkt om op basis daarvan het individuele krachtvoerrantsoen en de melkfrequentie voor de volgende dag te berekenen. Het systeem voert voor elke koe het ingestelde programma uit door automatisch de dagelijks bij te voeren hoeveelheid krachtvoer en de melkfrequentie te regelen op basis van de vrijwillige bezoeken van de koe aan de melkrobot.
3. De validatie van het regel- en managementsysteem voor melkvee

Voor alle uitgevoerde proeven onder bedrijfsomstandigheden was een melkstal beschikbaar uitgerust met een Prolion melkrobot en een krachtvoerautomaat. De totale stal, een loopstal, was verdeeld in twee gedeelten:
II. Het gedeelte met het automatische melksysteem. Dit bevat één of twee selectieboxen en een melkstand. Een selectiebox is een krachtvoerautomaat met een bestuurd in- en uitgang waar de koeien zich vrijwillig melden. Aan de hand van wat het regel- en managementsysteem heeft bepaald, krijgen de koeien in de selectiebox krachtvoer en worden zij doorgestuurd naar óf de melkstand óf het lig- of voedergedeelte van de stal. Alleen in de melkstand of in de selectiebox konden de dieren krachtvoer eten. Volgens de planning werden de koeien 2 maal per dag gemolken (hoofdstuk 3), 3 tot 5 maal per dag (hoofdstuk 4) of volgens een variabele melkfrequentie, van 6 teruglopend tot 2 maal per dag, in de loop van de lactatie (hoofdstuk 5, 6).

De eerste proef werd uitgevoerd om het gebruik van de individuele koegegevens, op grond waarvan beslissingen over het melkproces en de krachtvoerverstrekking worden genomen, te beoordelen en de werking op korte termijn van het volautomatische melken en de krachtvoerverstrekking na te gaan. Tijdens de laatste elf dagen was de melkrobot 24 uur per dag beschikbaar. In de procesbesturing werd een reeks variabelen en wiskundige formules verwerkt, die het bezoekpatroon aan de selectiebox en de krachtvoerverstrekking aangeven. Het bleek mogelijk, dagelijks het melkproces en de krachtvoerverstrekking automatisch te regelen. De verblijfstijd in de selectiebox, tezamen met het aantal bezoeken, bleek een goede maat te zijn voor de capaciteit van het systeem. Het gebruik van een selectiebox maakte het mogelijk het koeoverkeer en de krachtvoerverstrekking te regelen. Maar het koeoverkeer werd tussen de selectiebox en melkstand wel vertraagd, tot 5 minuten. De resultaten geven aan dat de koeien vanuit de selectiebox liever naar de melkstand gingen dan naar het voedergedeelte.

Met de ervaringen van de eerste proef werd een langere proef uitgevoerd, met een melkfrequentie en voederverstrekking die erop gebaseerd waren dat de koeien de selectieboxen vrijwillig bezochten. Gedurende 8 weken werd een groep van 29 koeien automatisch gemolken. Het ging er in deze proef om een individuele melkfrequentie en een individueel bepaald krachtvoerrantsoen per koe door te voeren, bij maximale bezetting van het automatische melksysteem. De gerealiseerde melkfrequentie lag tussen 2 en 5 maal per etmaal. Binnen één uur na het melken werden alle koeien die zich in een selectiebox meldden
naar het voedergedeelte gestuurd. Los daarvan werden koeien, die veel te vaak naar de selectiebox kwamen, naar het liggedeelte doorgestuurd. Bij alle andere bezoeken waarbij de koeien niet werden gemolken, konden zij zelf bepalen waarheen zij na het verlaten van de selectiebox wilden gaan. Voor meer dan 90 % van alle melkbeurten hadden de koeien zich vrijwillig gemeld. Het bezoekpatroon van de koeien bij vrije bewegingsmogelijkheid tussen het lig- en het voedergedeelte was voldoende om te komen tot een melkfrequentie van 4 maal per etmaal. De bezoeken van de groep waren gelijkmatig over de dag verdeeld. De tussenpozen tussen opeenvolgende bezoeken aan de selectiebox werden in hoge mate bepaald door de ervaring van de koe tijdens haar laatste bezoek. De naar verhouding kortste tussenpozen werden gevonden na vergeefse bezoeken aan de melkstand, wat meestal bezoeken waren, waarin minder dan 0,5 kg krachtvoer werd verstrekt. Vaarzen bezochten de selectiebox vaker dan volwassen dieren.

In de derde proef werd een groep van 24 koeien gedurende 7 maanden onderworpen aan een bepaald concept van melken en extra krachtvoerverstrekking. Er werden twee managementconcepten beproefd, te weten:

I. Een vaste melkfrequentie van 3 maal daags gedurende de gehele proef waarbij de krachtvoergift wekelijks werd bekeken volgens een in Nederland gebruikelijke standaard.
II. Een variabele melkfrequentie, van 6 maal per dag direct na het afkalven teruggelopen tot 3 maal per dag in de loop van de proef. De melkfrequentie en de individuele bijvoedering met krachtvoer werden dagelijks bekeken door middel van een expertsysteem, op basis van criteria voor de produktie.

In deze proef werden de koeien gemolken en gevoerd volgens een schema waarbij ze slechts 1 maal per periode van 4 uur werden beloond door ze te melken of krachtvoer te geven, of beide. De resultaten geven aan dat de koeien in 5,4 van de 6 perioden per etmaal het systeem tenminste een keer bezochten. Het percentage van de koeien dat 3, 4, 5 en 6 maal per dag werd gemolken, bedroeg resp. 106,9 % (±18,6), 90,5 % (±15,1), 93,9 % (±17,3) 79,9 % (±15,0) van de beoogde frequentie. Binnen 10 dagen na het afkalven raakten de koeien gewend aan het automatische melksysteem en bezochten zij in 97 % van alle melkbeurten de selectiebox vrijwillig om te worden gemolken. Gedurende de eerste tien dagen van de lactatieperiode en de rest van de lactatieperiode was de krachtvoeropname 97,8 % (±21,97) resp. 106 % (±18,88) van de beoogde opname. Er was voldoende tijd beschikbaar om een grote hoeveelheid krachtvoer (tot wel 18 kg/dag) in de selectieboxen en de melkstand te verstreken, zonder het koeverkeer daarmee op te houden. De reproduktiegoedgevens van de dieren van de twee groepen was niet significant verschillend. Voor de gehele lactatieperiode was de melkproduktie, op FCM-basis en per eenheid lichaamsgewicht, significant hoger bij de variabele melkfrequentie dan bij de groep met de vaste melkfrequentie.
4. Belangrijkste conclusies

- Het systeem dat het bezoek van koeien aan de selectiebox automatisch regelt, maakt een individuele melkfrequentie en krachtvoerverstrekking mogelijk en kan worden gebruikt als hulpmiddel bij de bedrijfsvoering in de melkveehouderij.

- Het melken en de krachtvoerverstrekking worden bij voorkeur geregeld door één desk-top computer, die direct is gekoppeld met alle regelapparatuur op het bedrijf.

- Er is een goede combinatie van selectieboxen en melkstanden nodig om een volledige regeling van de hoge melkfrequentie en de krachtvoerverstrekking te bereiken, alsmede de capaciteit van het automatische melksysteem te verhogen.

Om de doelmatigheid van het automatische melksysteem zo groot mogelijk te maken, wordt het gebruik van tenminste twee melkstanden in een verhouding van twee selectieboxen tot één melkstand aanbevolen.

- Er is voldoende tijd beschikbaar om de dagelijkse grote hoeveelheid krachtvoer alleen in het automatische melksysteem te kunnen geven. Dit maakt extra krachtvoerautomaten in de stal overbodig. Indien nodig, moeten beslissingen over de verstrekking van extra krachtvoer direct kunnen worden genomen en eenvoudig kunnen worden aangepast, d.w.z. terwijl de koe nog in de selectiebox of op de melkstand staat. Bij gebruik van vooraf bepaalde porties werd de beoogde hoeveelheid krachtvoer niet volledig gegeven.

- Het bezoekpatroon van de koe aan de selectiebox kan worden geregeld met de inrichting van de looproute, of door ze te belonen door ze te melken en krachtvoer te geven. Binnen tien dagen na de kalfdatum zijn koeien gewend aan het vrijwillige melken en de verstrekking van krachtvoer in het automatisch melksysteem.

Koeien worden sterk beïnvloed door hun ervaringen tijdens hun laatste bezoek aan de selectiebox, vooral met betrekking tot de beloning, niet zozeer door hun melkfrequentie of pariteit. De beloning met krachtvoer speelt een belangrijke rol bij de regeling van het bezoek van koeien aan de melkrobot. Koeien die gemolken behoren te worden en abusievelijk niet zijn beloond (d.w.z. zijn teruggestuurd), komen meestal kort na hun laatste bezoek bij het automatische melksysteem terug. Wanneer zij eenmaal de selectiebox zijn binnengegaan, gaan de dieren liever naar de melkstand dan terug naar de groep.

- Wanneer koeien de selectiebox vrijwillig kunnen bezoeken, is een melkfrequentie van 4 maal per dag haalbaar zonder dat de veehouder veel dieren naar de melkstand moet halen. Bij eenrichtingverkeer is een frequentie van meer dan 4 maal melken per dag mogelijk, zonder dat de boer daar veel extra's voor behoeft te doen.

- Er is altijd een kans dat de boer een klein aantal koeien zelf naar de melkstand moet brengen. De boer richt zijn regelmatige bezoek aan de stal zo in dat dit voor zijn
bedrijfsvoering het beste uitkomt, waarbij hij zowel rekening houdt met de melkfrequentie, het totale aantal melkbeurten per etmaal, alsmede de hoeveelheid fysieke arbeid die nodig is om sommige koeien naar de selectiebox te brengen.

- Storingen in het systeem die op korte termijn spelen, hebben slechts een kortstondig effect op het gedrag van koeien en op hun produktie.

- Wanneer koeien, bij wie de melkfrequentie en krachtvoerverstrekking volgens hun produktie zijn geregeld, worden vergeleken met koeien, die worden gemolken met een vaste frequentie en krachtvoer ontvangen zoals in Nederland gebruikelijk is, produceren de eerste meer melk op FCM-basis per eenheid lichaamsgewicht.
Related publications

1992


1993


1994


Robotic milking: state of the art. Proceedings of the Third International Dairy Housing Conference Orlando, Florida, USA. p. 92


1995

Sharon Devir was born to Hava and Ori Devir on October 21, 1958 in Petah Tikva, Israel. He is married to Michal, M.D. and has twin children: Timna and Eitam. In 1987 he completed a B.Sc. in Agricultural Engineering at the Technion - Israel Technical Institute. From 1986 until 1991 he worked as a research engineer in the field of dairy automation and management in the Zootechnology Division at the Agricultural Engineering Institute, ARO, Israel. While working at the Volcani Center, he completed a Master’s degree in Agricultural Engineering at the Technion - Israel Technical Institute. Between 1991 and 1995 he worked at the Livestock Engineering Department, DLO Institute of Agricultural and Environmental Engineering, IMAG-DLO, Wageningen, The Netherlands as a scientist on the integration of the milking robot into the dairy. He has recently been appointed chief scientist of S.A.E., Computerized Dairy Management System Division, Afikim, Israel.
Summary on Hebrew

S. Devir

Livestock Engineering Department,
DLO Institute of Agricultural and Environmental Engineering,
P.O. Box 43, 6700 AA Wageningen, The Netherlands
כותרת

- קיימים מספרים זמניים לפי התקצבה.thumb1 של מועדון gdolot של מועדון מרכז (למעל ה-
- 18 ק"ג בירוס) במערכי התליבת האוסטריתバルד, קרי במעדרת התוכנית
 籍ב' של קהילה הוא יגרע עלון מונח הפרות במונח. réfé שומ צוור עברית

 ula מדרג צופים במעריין צופים במער

- פרות סנגלברג והורגנסון מגרון מרכז על סמי ביצועים ימיים ייצובי יוצר
 籍י הרב מושבע שורב קלארית מספר גוף. כמר כו פרות אוליג דרך גסייה

 lamp משלובת ארוך יוצר בשונה לפרות סנגלברג באיתיות כובשה

מצเกษם המרכז הקצה להן על סמי הערכה שביעית במדドラマ בבר

תחודتعيين.
ארכיוסטרור התוף על ידי תיגמול מתאימה (בחליבת ואmaktadır מзор ורוסל). פורת גרסות לחדרגל לשיגור התמזגות (חליבת עצמאית ואבוד 
תקצאת המדור המורכז) ז如有侵权 מעשה מיים מיוג כונ嚴ים אלהיה.
המתגרגוגה פורת מושפעת עטיר תמנה שאיבת לא בקגור ואחרים בועדות 
הפגין לשיגור התיגמל. השפעה קספת ליצת על הפגוגה תיגרומ Yaş 
לاخلינו התיליבה ואגיל התיפה. תיגמל פורת בזמור מרכז הפיקד 
ושרב מעבר ריסוס ביתוי תיגרומ Yaş ריבוע התיליבה.

פForRow הצמאות התיליבה שניית מסיבות אלו מריצוחר (מתוינות) ולא עמשה 
תקלט בצבעד ואהמה לתיליבה ואורכים מי שזארחאיה שלחת כותריה 
לעד לאלת התיליבה, גוסות לחוזר מתו יזור המדות הפגוגה אצלאי הדיתוק 
מש. מכל מקום, חלוקות בצבעד השפעת גזゴגית בלבד על ביצורי פורת 
והפגוגה.

ל NAMES פיתוח שריון עמדה הפגינה, פורת מצידי פוג ועמדת התיליבה על 
ה.ImageIcon צ-fashion לזרורים הלאומית.

- ברמת בן התיפור מבקרים את עמדת התיליבה באפור אנטומי, קניין מעבר 
תרסיי בן אוזרי הריביצה והאותנש. יינת התילוב פורת בתדידות של ארבע 
פגוים בזמור לא יעקבות זירב תורת התחום התחלכי תботת פורת לעמדת 
התילובה. אינלי התיפור תונגוה חזר-כירוגין (מאזואר התאותמלрабיצת וא 
ל zdjęć) מאפפורת תדילות התילובה גבורה מארב פפגוים בזמור עמעורבות 
מורגבל של החפגה תבאתת פורת לעמדת התילובה.

- קיימת האפפוגרה הופפר נקשל פForRow שלן ביניו בארגוף עצבמת לעמדת 
התילובה. על ה.phiוות שלקורות את החרושתון של התילובה התדידות תבאתת 
服務或 פפגוים בזמור (הברקט 'ייזון') לעוגה הצורה עמעורבות-
морגבל בתNavBarת פורת לעמדת התילובה (בצעקר בת싶ו התילובה). ה.יון עילו על 
גיסר התמשק עדימה ביצוגי על פי חתך בניליי תייוור ההפגנה, ברמת 
של. התילובה התהיה תונזאת של שילוב של תדילות התילובה רגורייה, מسرعة 
פForRow ומפרעת היליבות מירבי מעשה שינתם לתילוב מתאימה למחנה 
"Rovit"
מצוקת עקרונית (על שום כל החרובים):
- слиיסת רבדה אוסומטיות של ביקרון חורבות ייחודיות הפוגעת בפוניה مؤססת ניידות
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פתא ואגפי השדיה התרשוד הגורשה מרעך מאשימים וקרקמים מרושעיםنظم האימוץ והביניים זאתר וראיה ולאלה עריצי השדיה. בשתייה
על מרעך מאשימים, ותאדות עלקית ההולכות המובסשת על מאשימים לכל
פר נבונד.

מסתע ניסיון השדיה התרשוד היתה הולכתו היחידה שלחיון דבר נוספים על שירה
תלהב היחידה בזאתה מתמדת פיצוץ. כמכן כל יסוד השכלת הרקע
מהיה שילוש על מרעך השדיה, קצאת המיתר המורצל והנוגע פיצוץ הפרוצר
על התנהלות הפרוצת והמעלת הים הרך בהולכות. דידות היחידה והג蚨 של
ביים. בטוחה התוכנית ציונית לפרס הווה ומורשתו אלא שירה קבעה כל
ה insan. הניסיון האתיקה הוא השילוש ופשר פיצוץ על שירה הליון ועל
התקשת פיצוץ ברחונל הרובוטים בפורח יניקות פיצוץ. עץ גדול לעצמית
מקצב זה עם התוכנית ציונית המשקתם העברת הפיצוץ. הפיצוץ המוסכם
למחרת מיצד כילוח התכנות של מרצבת הולכות האסקופה. השיטה במעלוף
ˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍˍ.detach-3

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הכותרת

שגרונה ליוודעה בחינתה בארוניברסיטי הקולג'יטי רוכג'ינן, הולנד

לאס כבלת תואר דוקטור

אב החפירות ארגנטינה 1995

הקדמה

1. הביאור זהзор מקח� עיפויות של מערכות בקבות ושילוח ואוטומציה שלמדות. ימי
ברח הבוח בניהה מתבצעת על ידי מערכות חליבת רובוטים. מוסר המחבר י יהודה
יושם מנשק פרטיה של שידור deben מנהיגות, הקצאת מזרחי רותגון
נפרדו של פתרת סטטיסטי (ללא ממשק עידונית). לא נמדדה של עקרונות
ה множות הדורסינו ל‹פת חליב הרובוטים,› ניגהו נתיבים שלבריה
נזרקה מבחרים בין, עיצוב במובָר, אֶל.restart אחר
רשלים ואוטומציה לשכונת. מתэтажה ניסורייה שדה יער, על מנת לבזר את
העייפות רככם עם של מערכות חליבת האוטומציה שלידנייה בשנייה החותר בחרוב
ה множות המחיא בחובור זה עידון. מחתלת הכור ירכוב השבינה דם
במוכן מחודש הקולג'יטי ברוכג'ינן, הולנד. במערך החישוב והחקור
שכל מוערכ המשמש להביעה שלידנייה חליבת והקצאת מזרחי יוצר על נמק יזרועים
שוכנים פָרוּ תזרות משחיתים עם מינוח המחיא הקולג'יטי - מונק וולק'ג', ביט-זָ'ג',
וירואל.

2. ממשק בקורר בחרת שלמה מערכות חליבת ואוטומציה: שטרגורות ומארגנים
על מערכות החליבת הרובוטים לשכונת בחרת במדל vỏ-y הסכום לא רק את שטרגור
של הפרט_symbol מוסך רובוטים בגבעת החליבת אילו גמסי תUnauthorized� בתקלת
האנושות והבחיותו. גידל הפרט_symbol אזורים האנושות, ריבית רובוטים החליבת. הפרט
נאנושות ובמקסים פרטניים מובקים. משבץ עם שידור צמאית שלחליב בחרת
רובוטים החליבת. בחרת 2ו. הפרט_symbol בזבוי עוד שלגזרית גידל עם מערית, החליבת
והאנושות נבזבז, שגון נחש והبِרייหาย משבירת. מנקודות שלומ מתחרים, מוערכות
חליבת ואוטומציה השפתיו את עלייתו היותר של dzi שלחץ זירות על כ''די העלאת דירורות החליבת
הנימשך בשכונת מחולשת פרטני יש
Hinang nu-oun mun nauin
Tai
Livestock Engineering Department,
DLO Institute of Agricultural and Environmental Engineering,
P.O. Box 43, 6700 AA Wageningen, The Netherlands

מערבת בקרת ושילוחה למשק
בrescia החלב הרובוטית

ת)new

שרון דביר

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מערבות בקיקה
وسائل למשק
ברפта מחול
הרובוטית

שהביר