Labour organisation on robotic milking dairy farms

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PROEFSCHRIFT

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Stellingen

1. Een stijging van de melkproduktie met 15 tot 20%, als gevolg van een verhoogde melkfrequentie bij automatisch melken, betekent dat minder melkkoeien kunnen worden gehouden om eenzelfde melkquotum vol te melken. Dit betekent echter niet dat in eenzelfde verhouding minder jongvee voor vervanging kan worden aangehouden. *Dit proefschrift*

2. Voor de kwaliteit en continuïteit van het melkproces bij automatisch melken is het belangrijker dat de veehouder zelf kleine technische storingen kan herstellen dan dat een permanent beschikbare onderhoudsdienst van de melkrobotfabrikant dit doet. *Dit proefschrift*

3. De beslissing om over te gaan van conventioneel naar automatisch melken zou gebaseerd moeten zijn op arbeidsorganisatorische en economische doelstellingen, maar zal uiteindelijk sterk beïnvloed worden door subjectieve overwegingen van de veehouder ten aanzien van deze doelstellingen. *Dit proefschrift*

4. Melkrobotinstallaties kunnen slechts zo goed werken als het strategisch bedrijfsplan waarin ze zijn opgenomen. *Dit proefschrift*

5. Met de landbouwkundige en toegepaste biologische wetenschappen als basis is het mogelijk door modelleren en simuleren van het samenspel tussen menselijke, technische en dierlijke componenten, effecten van zich in de realiteit afspelende interactieve processen te voorspellen. *Dit proefschrift*

6. Het feit dat de vraag naar specifieke agrarische software klein is, betekent niet dat de vraag nog klein zal zijn op het ogenblik dat hij voor de gebruiker beschikbaar is.

7. Een wetenschappelijk werk krijgt een meerwaarde als het in de meest actief én passief gebruikte taal van de wereld wordt geschreven. (A scientific work gets an additional value when it is written in the most active and passive common language of the world).

8. De machine isoleert de mens niet van de grote problemen van de natuur, maar stort hem er dieper in (Antoine De Saint-Exupéry).

9. De vergelijking van Mandelbrot leidt tot een figuur met een eindige oppervlakte en een oneindige omtrek. Een grafische weergave van dergelijke wiskundige vergelijkingen kan een moderne vorm van kunst worden genoemd.

10. De huidige problemen met de dolle koeienziekte tonen aan dat het streven om in Europa te komen tot een vrije markteconomie op gespannen voet staat met de beheersing van dierenziekten.

11. Het feit dat de consument meer betaalt voor een liter spuitwater dan voor een liter melk stemt tot nadenken zeker als men weet welke diverse techno-biologische processen er schuilen achter de produktie van die liter melk. Het is precies het laatste dat spijtig genoeg aan de aandacht van de consument ontsnapt.

Stellingen behorend bij het proefschrift "Labour organisation on robotic milking dairy farms"
van B.R. Sonck. Wageningen, 14 juni 1996

Aan mijn ouders
Aan Inge, Laurien en Siem

Voorwoord

Het onderzoek beschreven in dit proefschrift is uitgevoerd bij het Rijksstation voor Landbouwtechniek - Centrum voor Landbouwkundig onderzoek - Gent, bij het Instituut voor Milieu- en Agritechniek (IMAG-DLO) te Wageningen en bij de Vakgroep Agrotechniek en -fysica van de Landbouwuniversiteit eveneens te Wageningen. Dit onderzoek is gefinancierd door het Ministerie van Landbouw, Centrum voor Landbouwkundig Onderzoek - Gent en door het IMAG-DLO van Wageningen. De directeurs, respectievelijk de heren ir. H. Keymeulen en ir. A. Jongebreur wil ik danken voor de mogelijkheden die mij werden gegeven dit onderzoek in hun instituten te verrichten. Aan de uitvoering van het werk is door een groot aantal personen bijgedragen. Het verschijnen van dit proefschrift biedt mij de gelegenheid allen hartelijk te danken voor hun medewerking.

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Contents

Chapter 1

General Introduction

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1. Background of the study

Work in dairy husbandry and in agriculture in general, is characterized by a high degree of diversity. The labour objects in agriculture are mostly living plants and animals. The production depends more or less on natural conditions. It is this dependence on natural conditions and living objects which gives a peculiar character to the production activities in agriculture and makes that automation cannot easily be introduced as is the case in industry. Features of crops and animals, such as diseases, individual animal care, oestrus detection, etc. require a good deal of experience from the farmer (Frouws and van der Ploeg, 1988). Automation has to be complementary to the farmers' knowledge and skill which are indispensable in the production process. The introduction of new technologies implies the reorganisation of jobs and functions and the allotment of the jobs and functions to the various workers (Heming, 1992). As dairy farms are usually family farms in the Netherlands and even in Western Europe (LEI-DLO, 1994), these workers can be members of the family and a new labour planning can affect family life in a positive or negative way. These workers can also belong to a company working together with the farmer (e.g. contract workers) and thus a new labour planning may also change the degree of dependence on these companies. Due to the peculiar character of the production activities on dairy farms and the individual response of the farmer to continuously changing production conditions, standardized reorganisation measures cannot be applied. The farmer will have to consider which new technologies will fit into his current and future farm structure, organisation and management style.

The automatic milking system (AMS) is a new technology for dairy farms which gets increasingly more attention as a result of the evolution and developments described below. After the introduction of milk quota regulations in 1984, the number of farmers that abandoned dairy farming increased enormously. From the 1 593 000 dairy farmers in the former EU-10 in 1983, almost 40% left dairy production. In 1990 the number of dairy farmers amounted only to 974 000 (Debergh, 1992). Assuming that a large number of farms with 30 to 50 cows will cease their dairying activities, Muller et al. (1993), expect a similar decrease (40%) towards the year 2005. The resources of the closing farms, e.g. milk quota and farmland, may find their way to those which continue. The latter are faced with the challenge of upgrading their farms into a more specialized structure. In addition, this specialization (read scaling up) will have to be realized within the farm-intrinsic limitations (e.g. investment potential), under more stringent environmental and ecological requirements and under the critical eye of the consumer. Therefore management, which can be described as a decision-making process in which limited resources are allocated to a number of production alternatives (Kay, 1986), has become increasingly important in dairy farming. An improved farm management will help to reduce the production costs and consequently contribute to maintain farm income. Automation and information technology can play an important role in improving management by providing accurate and consistent information for making decisions (Boehlje and Eidman, 1984). Besides the precision regulation of a process, automation includes usually also a change of labour aspects. On expanding farms it will be important to deploy the labour force as efficient as possible. Automation can open new perspectives, since it can replace tasks of the farmer and contribute to labour savings and a reduction in the work load. New activities will arise with automation leading to task enlargement and enrichment (e.g. programming, operation and maintenance of new machines) which may uplift the farmer's status. Humanization of the work and the work environment has to be a goal at any time. In this context it is worthwhile to mention the Working Environment Act, which came into force in 1983 in The Netherlands and focuses on safety, health and well-being at work. Thanks to such legislation at national and European level, the awareness is slowly growing that an improvement in quality of working is not only advantageous to the farmer with his education, his professional skill and experience, but may also be a tool to increase the efficiency and productivity of a farm (Fruytier, 1986). New technologies such as the automatic milking system, might have negative effects too, e.g. on the labour conditions. Regular calls for assistance with the system or a high failure frequency can disturb the labour planning and cause stress to the farmer and his family.

A study of different management styles revealed common ideas amongst interviewed farmers about the features of an optimal farm (van der Ploeg and Roep, 1990). Reduction in the work load, a weaker bond to the farm, more opportunities to discuss work with other persons, more personal freedom in what one wants to do, etc., were mentioned. This was realized to a certain extent through the automation in pig and poultry husbandry, arable farming and horticulture. The dairy farmer however is still tied to the daily obligation of milking at unsocial hours of the day. Despite the use of milking machines equipped with an increasing number of sensors, attachment of the teatcups and milking proper still require the presence of a human operator. In addition, the application of labour saving devices transformed milking into a monotonous job with a small number of tasks that have to be repeated frequently. Milking and make-ready and put-away activities of milking still require about 30% of the total labour requirement on dairy farms (Ordolff, 1986; Sonck, 1993). Therefore automation of the milking job might result in important labour savings.

Against the background of developments and the evolution in work ethics in dairy husbandry, the automatic milking system might contribute to a sustainable agriculture, described by Gips (1988) as ecologically sound, economically viable, *socially justified and human.* The automatic milking system (AMS) implies more than a robot which attaches the teatcups to a cow's teats. The AMS comprises a milking robot with one or more milking stalls, facilities in the cowshed to control the cow traffic towards the milking point (e.g. selection boxes) and an expert system that controls and makes decisions related to cow individual milking frequency and concentrate and even roughage supplementation (Devir, 1995; Ipema and Rossing, 1987). Production efficiency is likely to increase with this individual cow approach (Maltz et al., 1992). Because the farmer is not present each time a milking or feeding decision is needed, processes will have to be controlled by autonomous subsystems based on new micro-electronic applications in the dairy farm. An integrated dairy control and management system as described by Devir (1993) will have to support AMS working.

Several research institutes and collaborating firms have started pilot-scale experiments with AMS's. Systems on the market and under development are summarized in Table 1. Rossing (pers. comm.) mentioned that a 100% successful attachment of the teatcups is yet not possible. Too slow and inaccurate systems, inaccessible teat positions and difficulties in correctly locating the teats are problems that still have to be solved with the current systems.

***Table 1.** Information of automatic milking systems on the market and under development (Rossing, pers. comm., 1996)*

a. Systems on the market

Manufacturer	*Number of installations*	*Farms*	*Principle*	*Remarks*
Lely (The Netherlands)	28 on 20 commercial farms	3 farms in Belgium rest on farms in The Netherlands	one box system, one arm with a milk rack with 4 teatcups	most systems used for continuous milking
Prolion Development (The Netherlands)	28 on 4 experimental farms and 24 commercial farms	1 farm in Canada 1 farm in France 1 farm in Germany 3 farms in Japan 22 farms in The Netherlands	1, 2, 3 or 4 box system with one robot, a robot arm and an arm with a milk rack with 4 teatcups	system used for continuous milking and milking at fixed intervals

b. Systems under development

Manufacturer	*Number of installations*	*Farms*	*Principle*	*Remarks*
AFRC, Silsoe Research Institute (UK)	2 on experimental farms	1 in UK 1 in Sweden	one box system one arm attaches the 4 teatcups one by one	system now under development by Alfa Laval
CEMAGREF (France)	1 on an experimental farm		one box system 4 arms each attaches one teatcup	
Düvelsdorf/Westfalia (Germany)	2 on experimental farms	2 in Germany	one or two box system, one arm attaches the 4 teatcups one by one	system taken over by Westfalia
Gascoigne Melotte (Germany)	2 on experimental farms	1 in USA 1 in The Netherlands	one box system one arm with a milk rack with 4 teatcups	teatcups are attached from behind between the hind legs

So far, most of the attention of researchers was focused on technical problems, milk quality and cow behaviour around the AMS (Ipema et al., 1992). This dissertation focuses on a rather unexplored discipline of automatic milking : the future requirements concerning human labour and labour (re)organisation vis-à-vis the complex interaction between cow and AMS on the dairy farm of the future. Research in this thesis was carried out within the DLO-programme 105, 'Innovative technology for dairy husbandry', and is started as a joint activity of the DLO-Institute of Agricultural and Environmental Engineering (IMAG-DLO), Wageningen Agricultural University (WAU), The Netherlands and the CLO-Research Station of Agricultural Engineering (CLO-RvL) in Merelbeke, Belgium.

2. Goals of the study

The main goal of this research is to study the effects of automatic milking on the labour organisation of a dairy farm at operational (short-term) and tactical (medium-term) level. The study can be divided in a number of research issues :

(a) What is the capacity of a milking robot ? In determining the amount of human labour that can be replaced by the milking robot, the capacity of the milking robot forms an indispensable basis for calculations of labour requirement of the AMS.

(b) What are the remaining "milking" operations and work elements of the farmer according to the chosen work method with the AMS ? Because cows will be kept closer to the milking system, other grazing systems than unrestricted grazing where cows are pasturing day and night will have to be applied with automatic milking. Therefore, the question requires an evaluation of the work methods with an AMS and grazing systems. A grazing system refers here to a specific time distribution of "keeping cows in- or outdoors" on daily and yearly basis.

(c) What are the effects of different AMS management strategies on the daily labour requirement and labour organisation at operational level ?

(d) What are the effects of different AMS management strategies on the annual labour requirement and the labour organisation at tactical level ? What are the possible annual labour savings in comparison with conventional milking farms ?

(e) The results of the above-mentioned research questions will have to give indications to discuss labour quality and the quality of life of the farmer on robotic milking farms.

To answer these questions, data were collected on commercial farms with an AMS of the 'Prolion Development' type (Bottema, 1992; Hogewerf et al., 1992) and subsequently used in *simulation models* and *task time modules*.

To study the milking capacity of a milking robot, the processes of the milking robot, of the cow and of the interaction milking robot-cow are first modelled statically. This simple model must allow to judge different types of milking robots and to estimate the impact of factors that affect the milking capacity of a milking robot (and must allow to give answers to question a).

To answer question b, labour time data which form a basis for task time modules were collected on commercial farms. Task time modules calculate labour requirement at operational and tactical level conform with farm-specific circumstances. IMAG-DLO has developed several task time programs, for example for field operations, cattle management, horticulture and arboriculture. Within the framework of this project, new task time modules for dairy farms with an AMS need to be developed.

To study alternative set-ups of an AMS and the effects of different AMS management strategies on the labour requirement at operational level, a simulation model has to be developed. This model should deliver additional labour requirement data at operational level and on the performance of the milking robot, the AMS configuration, the interaction man-cow-milking robot, the herd structure and size, etc. (answer to question c)

The intention of the project is that these simulation models and task time modules can work autonomously and provide detailed information (and give answers to questions a, b and c). Each of these subprograms will finally be used as part of a labour budgeting program where the information of the models and task time modules will be used as input. A labour budget compares labour supply and labour demand for the farm as a unit (Kroeze, 1982). The output of the labour budgeting program should make it possible to formulate and to answer question d. Case-studies with the above-mentioned simulation models, task time modules and labour budgeting program and the experiences with the AMS's on commercial farms will have to give indications on the level of quality of working life on these farms (answer to question e).

3. Outline of the dissertation

Chapter 1 introduces the thesis with the background, the goals of the research and the outline of the dissertation.

Based on a literature study, the progress in dairy technology is described in chapter 2. The automation of teatcup attachment necessitates the automation of all other operations normally performed during the milking process in a conventional milking parlour. This chapter contains a view on the state-of-the-art in the automation of all these 'milking operations'. Chapter 2 also addresses the consequences of automatic milking on milk production and milk quality, on animal health and welfare as well as the environmental, socio-economic effects and labour aspects.

Before studying the interaction man-cow-milking robot, knowledge is required about the milking robot itself and the interaction milking robot - dairy cow (Fig. 1 : A). Therefore, we established first in an operational research the milking capacity of a milking robot. The milking process with the milking robot is studied by means of cycle analyses which resulted in the definition of a formula for tuning (chapter 3). This formula offers the possibility to estimate the capacity of a milking robot with *n* milking stalls in line. Alternative set-ups of the milking stalls of an AMS are also discussed.

To register the operations that still have to be performed by the milker with automatic milking, a labour research was carried out on commercial farms where AMS's were installed. Milking was done twice a day and cow traffic was controlled by the milker. The interactions farmer - milking robot and farmer - dairy cow are focused here (Fig. 1 : B1 and B2). From this study, as described in chapter 4, we derived a task time module which calculates the labour requirement for automatic milking with a human-controlled and computer-controlled cow traffic, each combined with different cow grazing systems. A case-study is also presented here.

Chapter 5 contains the development and description of a simulation model of automatic milking under different configurations and AMS management strategies. The relation between quality of the milking process and different AMS management strategies is discussed in this chapter (Fig. 1 : C).

From a labour organisational point of view, the success of the automatic milking system will depend on the degree of independent functioning of the total system. Technical malfunctions and unwanted cow behaviour might require additional work, disturb the daily labour (organisation) routine, tie the dairyman to the AMS and cause mental stress. Based on the simulation model of chapter 5, a research was executed to study the effects of automatic milking on the daily labour organisation on the farm. This research is described in chapter 6 and focuses on the interaction farmer - AMS (Fig. 1 : D).

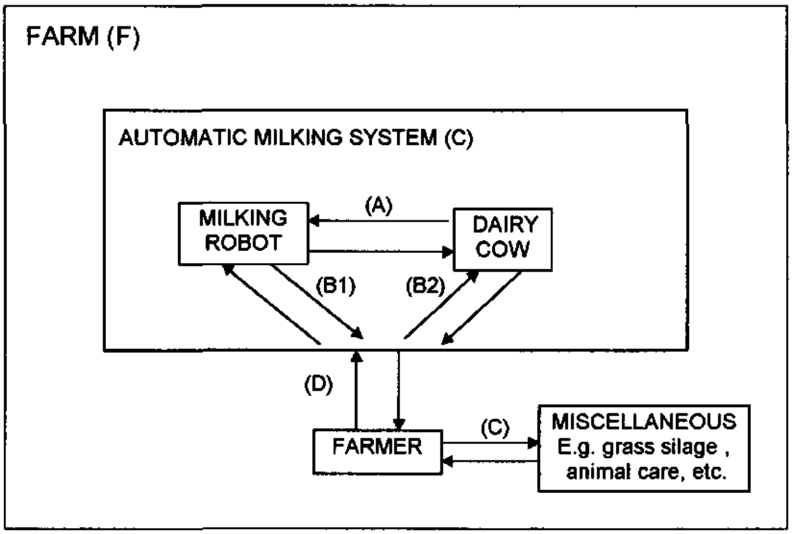

***Fig. 1.** Location of the research topics in a schematic presentation of an AMS farm*

To study the effects of automatic milking and the application of different management strategies on the annual labour requirement and labour organisation, the IMAG-DLO labour budgeting program was used, combined with the above-mentioned simulation models and calculation modules. Effects of automatic milking on other-than-milking operations, such as grass silage production were considered too (Fig. 1 : E). Chapter 7 describes the computational method to budget farms and illustrates the use of the programs by means of model farms. The total farm is focused here (Fig. 1 : F).

The study is closed with a general discussion, conclusions and recommendations for further research (chapter 8).

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Chapter 2

Automation of labour with regard to automatic milking : possibilities and effects

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Abstract

Automation of milking is not limited to the automation of the attachment of teatcups to a cow's teats but involves also other milking operations. In this chapter the milking operations in a conventional milking parlour are first identified. Second the state-of-the-art in the automation of ordinary milking operations and the integration of devices specific to the automatic milking system (AMS) are presented. Finally, the effects of the implementation of a milking robot on milk quality, cows, farmer and farm are evaluated. This evaluation is based on the current knowledge of and prospects for automatic milking.

From literature, we concluded that technical solutions for the automation of each milking activity performed in conventional milking parlours are available today. However the developed devices do not always attain the same degree of accuracy as the milker. Integration of these devices in the automatic milking system has to go together with an improvement of these devices. No current automatic attachment system guarantees a 100% successful attachment of the teatcups. However, much progress has been made during the last years and attachment scores of 85 to 99% have been reached. As some cows in a herd may show a low frequent visiting pattern to the selection unit or milking unit, only an attachment score close to 100% is acceptable. Behavioural studies have shown that cows are able to use the AMS voluntarily and they become accustomed to it. So far, no investigations have been carried out on voluntary visits of cows to an AMS if cows are grazing. More research is needed on the integration of the AMS in new and existing loose housing systems. The experiences with the layout of AMS cowhouses are limited to experimental farms. Several proposed layouts by researchers are not yet investigated.

Activity, milk yield, milk temperature, quarter milk conductivity and concentrates are data that can be gathered on-line and are suitable for detection of oestrus, mastitis, infectious diseases, metabolic disorders and lameness. Management information systems which translate these data into essential information which is comprehensible for the farmer, need to be developed for automatic milking systems.

An increased milking frequency based on voluntary visits of the cows to a milking point will raise the milk yield with 5 to 25% and positively affect the animals' health and welfare. Negative effects such as teat damage, due to a higher duration of machine milking, and stress require further research on respectively milk technical aspects and behavioural aspects. The effects of milking frequency on reproduction require more attention in future research.

The prospects on environmental effects are in general positive. The socio-economic effects as well as the effects on labour aspects will strongly be determined by the reliability of the automatic milking system. However, the expectation is that labour requirement will be reduced and labour conditions will improve. Few and rough estimations on expected labour saving with automatic milking were found in the literature. The following chapters deal in more detail with the effects of automatic milking on labour and labour organisation on dairy farms.

Key words : automatic milking, labour, dairy cows

1. Introduction

A successful robotization of milking on a dairy farm requires first of all an evaluation of the influences and the consequences. These are important for the system performance later on. Robot projects require therefore a managerial approach with an integral and multidisciplinary project approach (Rampersad, 1992). On the dairy farm it has to result in a complete system where men, cows, computers and resources work efficiently together.

Automation of milking is not limited to the automation of the attachment of teatcups to a cow's teats but involves also other milking operations to be automated, e.g. determining the cleanliness of teats, teat preparation, udder stimulation, etc. In this chapter we will identify the milking operations in traditional milking parlours. Second, the state-of-the-art in the automation of ordinary milking operations and the integration of devices specific to the AMS are presented. Finally, the effects of the implementation of a milking robot on milk quality, cow, farmer and farm are evaluated. This evaluation is based on the current knowledge of and prospects for automatic milking.

2. Milking operations in conventional milking parlours

A conventional milking parlour is a building with a limited number of milking stalls and milking units to which cows are brought to be milked. The equipment in a parlour is arranged for easy movement of the animals and to enable the milker to manage several milking units without undue effort (Clough, 1977). Work studies performed in milking parlours, give a good account of all milking operations and their respective labour requirements. As an example, Table 1 shows the labour requirement of milking routines and the effects of increasing automation or omission of certain operations on the theoretical labour productivity of a herringbone milking parlour (without limitation of the number of milking units) (Sonck et al., 1991). In a herringbone milking parlour cows stand at an angle of about 30° on both sides of the pit in which the milker works. In recent work studies the labour requirement for milking in stanchion barns with rail milking (a system in which the milking equipment is suspended from a rail mounted on special supporting levers) and with conventional units with automatic change of cluster was respectively 1.17 and 1.25 man-minutes per cow per milking. A labour requirement of 0.90 and 1.12 man-minutes per cow and per milking was registered in resp. automatic tandem parlours and herringbone milking parlours (Keller, 1994). In a tandem layout the stalls are arranged in line on one or both sides of a pit in which the milker works.

3. Technical solutions with regard to the automation of milking operations

3.1. Voluntary visit of cows to the milking point

With traditional milking, the cows are collected by the milker in a waiting area in front of the milking parlour and enter successively the milking parlour with a little help of the milker or with the aid of a moving fence.

Table 1. *Labour requirement (min/cow per milking) and theoretical labour productivity (cows/h) in a herringbone milking parlour in relation to increasing rate of automation and omission of milking routines (Sonck et al., 1991)*

Milking routine	*Time*	*Increasing rate of automation and omission of milking routines ------>------>------>------>------>*									
	(min)	*Omission of*				*Automation of*				*Omission of*	*Automation of*
		Stripping	*Foremilk*	*Concentrates supplementation*		*Cluster removal*		*Cow identification*	*Opening and closing doors*	*Udder preparation*	*Disinfection teats*
Let in/out cows	0.25	0.25	0.25	0.25	0.15*	0.15*	0.15*	0.15*	-	-	-
Concentrates supplementation	0.10	0.10	0.10	-	-	-	-	-	-	-	-
Wash, dry and inspect udder	0.35	0.35	0.35	0.35	0.35	0.35	0.10**	0.10**	0.10**	-	-
Foremilk	0.10	0.10	-	-	-	-	-	-	-	-	-
Attach cluster	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Remove cluster	0.10	0.10	0.10	0.10	0.10	-	-	-	-	-	-
Check production	0.15	0.15	0.15	0.15	0.15	0.15	0.15	-	-	-	-
Stripping	0.30	-	-	-	-	-	-	-	-	-	-
Disinfection teats	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	-
Miscellaneous	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Man time (min/cow)	1.72	1.42	1.32	1.22	1.12	1.02	0.77	0.62	0.47	0.37	0.30
Milking capacity (cows/h)	35	42	45	49	54	59	78	97	128	162	200
Required number of units with a machine milking time of											
5.00 min	5.09	6.71	7.18	7.73	8.36	9.80	12.99	16.13	21.28	27.08	33.33
6.00 min	6.04	8.03	8.59	9.24	10.00	11.76	15.58	19.35	25.53	32.43	40.00
7.00 min	6.98	9.34	10.00	10.76	11.64	13.73	18.18	22.35	29.79	37.84	46.67

* Improvement of the entry and exit of cows by using a gate that forces the cows to the milking parlour.
** The use of a preparation stall or 'prep-stall'. Udder preparation includes only drying and inspection of the udder.

Where animals are allowed to graze and an automatic milking system is in use, the main issue is how far cows are prepared to walk to be milked. The consensus of opinion is that cows are prepared to walk up to a few hundred metres (Moncaster and Parsons, 1987) but this has yet to be supported by experimental evidence. Where cows are kept indoors in free-stalls, behavioural as studies show that dairy cows visit the concentrate dispensers up to 15 times, the roughage feed fence up to 10 times, the watering trough about 5 and the cubicles about 9 times per day (Baehr, 1983). In feasibility studies with voluntary milking in automatic feeder stations (Rossing et al., 1985 ; Rabold, 1986 ; Ipema et al., 1987 ; Grimm and Nuber, 1988) the motivation to enter the milking box seems to be based more on the desire for concentrates than on the impetus to be milked. Therefore voluntary milking systems must be combined with automated feed dispensers. The same researchers have shown that some cows will visit an AMS too often which strains the capacity of the system. Others will visit the system too infrequently and have to be fetched by the farmer (Ipema et al., 1988). Ketelaar-de Lauwere (1990; 1992) and Metz-Stefanowka et al. (1989) show that the use of a selection unit between the lying and feeding area increases the number of visits of cows to an automatic milking system when the only route from lying area to the feeding area is via this unit (forced on active selection). Passive selection (cows decide themselves whether or not they visit the selection unit) can be as effective if preceded by a training period of active selection (Ketelaar-de Lauwere, 1992). Hopster et al. (1988) describe that the concentrate dispensers are fewer visited when the cows have to walk far (more than 15 metres) or have to leave the cowshed. This implies that the location of a selection unit (SU) and the milking unit (MU) in the cowshed have to be chosen carefully. A location near the feeding area makes the SU and MU more attractive to the cows (Metz et al.,1987a; Kempkens, 1989).

From a research of Wierenga and Hopster (1987) it appears that cows react to acoustic signals which announce the possibility for a cow to take up concentrates at a feeding station. The response to the signal was different from cow to cow and this calling method is therefore not suitable in automatic milking.

Devir (1992; 1993) developed a Dairy Control and Management System to control on-line the daily milking and individual concentrates supplementation routine. A field test with this system proved that a control of automatic daily milking and individual concentrates supplementation routine based on voluntary visits is possible (Devir et al., 1993). In addition, controlling and manipulating the cows' visiting pattern may result in a better distribution of the visits throughout the day.

3.2. Requirements for an automated and robotic milking stall

The automatic system should be able to milk a cow in the same professional way as a milker does. In a conventional milking parlour, the milker's dexterity enables him to avoid unwanted actions of the cow. With fully automated milking, technical means have to replace the herdsman and avoid injuries to cows and damage to equipment. Jacobson and Rabold (1983) and Middel and Oenema (1985) proposed mechanical devices to keep the cow's legs in the desired position : upwards moving footplates or a special metal plate to spread the hind legs. Mottram (1992b) found however that an angled central ridge between the hind legs caused a significant increase in the number of movements of the hind legs. To facilitate teat location by sensors it is important that the cow remains stationary and that cow movements are limited. Furthermore the hind legs have to be spread sufficiently so as not to obstruct the accessibility of the udder from the front and side. Montalescot (1986) designed a robot arm which was able to withstand kicks from a cow.

Ordolff (1987) showed that monitoring the activity of eating and fluctuations of load on the hind legs is useful to indicate the likelihood of unwanted cow reactions. Industrial sensors, such as capacity or ultrasonic transducers when linked to fast reacting control units and robotic arms can sense the distance between mechanical equipment and a cow and may be used to avoid collisions (Ordoff, 1987).

3.3. Cow identification

Gathering information of a cow at the automatic milking system starts with identification of the cow. Research on automatic animal identification has been in progress since the 1970's in England (Street, 1979), the Netherlands (Rossing, 1980), Germany (Pirkelmann and Stanzel, 1976), and the United States (Byrne, 1977; Hanton, 1981; Holm, 1979; Rodrian, 1981; Sigrimis and Scott, 1981). Animal identification with the passive transponder system has its application in various fields, such as feeding stations, calf drinking stations and milking parlour identification (Spahr et al., 1987). The system of injected identification transponders still shows some problems for use with automated electronic identification applications for cattle, for example in automatic milking (Spahr and Surber, 1992). Loss of injected units before complete healing with baby calves was the greatest cause of failure in trials of Spahr and Surber (1992). The short action radius of the implanted transponders (only 30 - 40 cm) in comparison with passive responders worn on a collar around the neck (60 - 80 cm) and ear-mounted responders (40 - 60 cm), is a serious limitation which has to be overcome before implants can substitute the collar-mounted responders (Rossing and Spahr, 1992). A directive of the European Union on the identification and registration of animals states that by the end of 1996 the Council of Ministers of the European Union shall decide on the feasibility of introducing electronic identification. If the use of the current identification transponders is officially no longer allowed, two new types of transponders will be introduced viz. a simple transponder with only the unique number of the animal, and a transponder which can incorporate sensors that have extended information storage capacity (Rossing et al., 1994).

3.4. Automation of premilking stimulation

Manual udder preparation including cleaning, foremilking and teat/udder massage during about 60 s prior to machine milking is called premilking stimulation. Such operations require to be automated with automatic milking.

Once a cow is positioned in the milking stall of an AMS, a system should determine the difference between clean and contaminated teats and inspect all four teats in a few seconds. The use of a video camera to obtain images of the teats has been examined (Gouws, 1993). Algorithms have recently been devised to detect blemishes on potatoes (Marchant, 1990) and a similar vision technique has been suggested for teat inspection by Marchal et al. (1992). Mottram et al. (1991a) devised a method of rotating an optical sensor system around the teat. An analysis of the spectral properties of the reflected light from the teat (wavelength scanning) gives an indication of the status of the teat (Bull et al., 1993). This method requires however further research. Mottram (1993) compared two methods of teat inspection : the percentage of area of a teat obscured by contaminants from photographs using manual vision techniques and the weight of material removed by swabbing the teat. He concluded that the weight of dirt removed from a teat does not correspond with the area contaminated. Further work is needed to determine whether the weight of dirt or the area contaminated is more significant for the bacterial contamination of milk (Mottram, 1993). Mottram (1992a) developed a teat cleaning device which has a piezo-electric sensor at the base of the cleaning mechanism to detect the impacts of particles falling from the teat as a result of the cleaning action. The assumption is that cleaning is complete when the particle impacts have stopped. Hogewerf and Kornet (1995) found differences in light reflection between teat skin and dry manure, and between dry and wet manure. Further research is required to investigate the possibilities to detect manure on teat, by means of light reflection.

Udder cleaning can be executed by rotating brushes or discs (with or without water supply), as designed by Jardin (1981 and 1982) and Tröger and Mielke (1984) and applied in a Dutch milking robot (Birkendorf, 1990; Van der Linde and Lubberink, 1992). Westhoff and Liu (1992) found that an AMS with a rotating udder/teat washing brush assures milk of acceptable quality. In a comparison between two automatic cleaning devices namely a rotating brush and a device which sprays water in the teatcup liner after attachment (Bottema, 1992), Schuiling (1992) found that with both methods teat contamination was still visible after cleaning, although results are better than without cleaning. In addition a positive effect of the rotating brush on milk ejection was found in this research. The milking robot of Lely Industries uses a roboting device with towels (Dalebout, 1993). Results are yet not known. At IMAG-DLO, Hogewerf (1995) is testing pulsating jets of water to clean the teats of a cow. The pulsating jets have a cleaning and possibly a milk stimulating effect.

A good stimulation of the milk ejection is needed for a smooth milk production (Worstorff et al., 1987; Hamann and Dodd, 1992). Mechanical stimulation methods have to replace manual stimulation in automatic milking. Compressed air at 50 kPa can be supplied to the pulsation chamber of the teatcup during the first minute of milking (Tröger and Lohr, 1967; Matthes et al., 1975; Tröger and Wehowsky, 1992). By increasing the pulsation rate and confining vacuum in the pulsation chamber to a maximum of 26 kPa during the first minute of milking, a vibratory effect is created comparable with the effect of a 60 s manual stimulation (Mayer et al., 1985; Worstorff et al., 1987). Other methods are the interval positive pressure pulsation system (Wehowsky et al., 1982; Tröger and Wehowsky, 1992) and the alternating pulsation frequency system (Thum et al., 1987). Worstorff and Prediger (1992) reported on the available commercial devices for premilking stimulation based on vibration stimulation. From literature, we can conclude that mechanical stimulation is suitable for automatic milking systems.

Automatic udder preparation requires also a system to separate the first squirts of milk with a higher somatic milk count (Maatje et al., 1983; Fernando et al., 1985) and a higher risk of contamination. Dorofeev (1987) designed a device based on a chamber with a float to collect the first squirts of milk. Torsius (1987) reported on a device for cleaning the teats and separating milk with a too high an electrical conductivity which indicates a too high a somatic cell count. Scheidemann (1990) used a device which diverted the milk from single quarters by a second pipeline after measurement of the electrical conductivity. Prolion (1993) separated teat cleaning water together with the foremilk in a separate container. The switch between cleaning water and milk is performed by means of valves installed on a milk rack.

3.5. Locating udder and teats

In automatic milking locating the udder and the teats must be done by means of sensors. First of all, a coarse locating of the udder (and teats) has to be performed. Information on the position of udder and teats stored in a computer, can speed-up the search and attachment procedures. The udder position can also be derived from the position of the cow relative to the milking stall by employing mechanical or electronic location sensors (ultrasound, optical distance or laser sensors) (Artmann, 1990). Udder contours can be measured with contact sensors or determined by an ultrasonic array or a vision system (Fig. 1.; Artmann, 1990. Gouws, 1993). As the teat positions are cow specific and because the geometry of the teats and the udder can change enormously during one lactation, with lactation year, during milking itself and with the moment of milking, a flexible teat searching and locating system is required (Schillingman, 1992). The following methods are applied for teat localisation :

- two ultrasonic sensors for a rough location of the teats and a rotating ultrasonic sensor for fine location (Hogewerf et al., 1992)
- an ultrasonic system with 8 ultrasonic sensors, which measures and evaluates up to 3 echoes per sensor (Artmann et al., 1990).
- a vision system based on a CCD camera, laser diode with collimator, vision processing card and a PC. Binary pictures are evaluated by software and the position of the teats is calculated (Artmann, 1992).
- tactile sensors and a database of teat positions for rough location of the teats in combination with a matrix of 8 infrared light beams for fine location (Street et al., 1992).
- a combination of stored data of teat positions, ultrasonic sensor and a frame with light barriers (Scheidemann, 1990; Dück, 1992).
- a combination of database with teat positions relative to moving vertical plates on stall sides and front, and a teatcup with a liner provided with an inflatable ring that swells under air pressure. This has the effect of centering the teat (van der Linde and Lubberink, 1992).
- a combination of a laser plane and a CCD camera for rough location, two lasers to get the four teats' co-ordinates and a matrix with infrared barriers around the teatcup for fine location. The

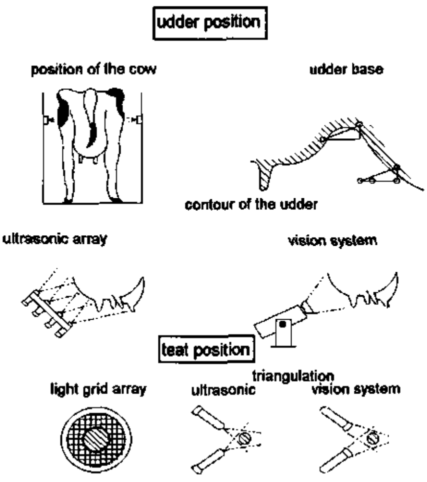

***Fig. 1.** Sensing methods for teat location*

intersection of the laser plane with the teats generates a scene for further calculations by triangulation (Marchal, 1990; Marchal et al., 1992).

- Dalebout (1993) reported on a system with one laser which quickly and accurately locates the teats. No details are given about the search procedure of the laser.

Optical systems are not so recommended for teat location because of the high costs involved, the risk of damage and contamination and the computing times which make the system to slow (e.g. with image processing).

3.6. Teatcup attachment

Teatcups have to be fetched, brought under the cows' udder, positioned centrally under the teats and finally moved over each teat. This teatcup attachment can be achieved in different ways (Fig. 2.). The teatcups can be handled individually or in group as a module. The robot (arm) and the teatcup(s) can be separate units or one assembly. If the robot and the teatcups are separate, one robot can serve more than one milking stall.

Table 2 summarises the attachment score (percentage of attachments that are successful) and the time for attachment achieved with different locating and teatcup attachment methods mentioned in literature. Although considerable progress is made, the figures show that further research on the improvement of the success rate and a decrease in the attachment time is desirable. Attachment scores of 99% have been achieved recently for the Prolion Development and Lely Industries milking robots (Rossing, 1996, pers.comm).

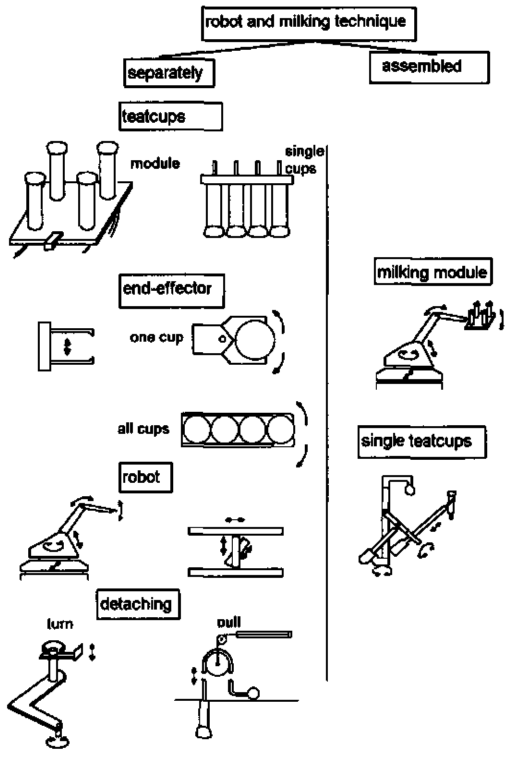

***Fig. 2.** An automatic milking system assembly*

***Table 2.** Attachment score and time for attachment : literature overview*

Authors	*Attachment score*	*Time (min/cow) (attachment of four teatcups)*
Artmann (1992)	70% (e.1) - 94 % (e.2)[a]	7.5
Marchal et al. (1992)	41.7% - 78.9%	< 1
Street et al. (1992)	68%	2
Hogewerf et al. (1992)	64.1% (e.1) - 88.5% (e.2)	3.12 (1 attempt in 35 s)
Sonck (ref. Swartjes, 1993)[b]	70.1%	1.35

[a] e.1 and e.2 refer to results of a first and a second experiment
[b] The same type of automatic milking system was used as in the experiment of Hogewerf et al. (1992)

3.7. Stripping

A good stimulation is one of the first conditions to achieve low stripping yields (Buchholz, 1977; Mayer, 1983). Omitting stripping can result in milk losses of 5 to 15% and a higher risk of udder diseases (Klein et al., 1985; Ebendorff et al., 1985; Ebendorff et al., 1987; Göft and Dethlefsen, 1992). Although mechanical stripping systems are developed (Rudovsky et al. (1985); Klein et al., 1985; Westfalia Separator, 1991) following precautions mentioned by Ordolff (1993) will also result in low stripping yields : maintaining a stable position of the teatcup in general, a diminution of the milking vacuum which reduces the velocity of the milk flow and the force to suck in teat tissue, increasing the weight of the milking unit (Thiel and Mein, 1977), well designed technical details e.g. the ratio diameter/height of the mouthpiece of the teatcup liner (Mayntz, 1981) and controlling the operation of the milking unit according to individual milking characteristics of the cows (Grimm, 1990). Slowing down the opening speed of the teatcup liners, reduce stripping yields with more than 20% compared to standard liner movement (Schlaiß et al., 1994). Alfa-Laval (1994) proposed a flow-controlled milking system with an adjustable time interval of the end-milking phase. This phase starts when the milk flow drops below a low-flow level (200 g/min), automatically the vacuum level decreases and the pulsation becomes slower with a short suction time. This avoids milking when no milk is flowing.

The above-mentioned precautions might be taken into consideration for automatic milking too.

3.8. Removal of the teatcups

Automatic milking systems require an automatic removal of the teatcups. Fully-automatic cluster removers are designed to remove the cluster from a cow at the end of milking when milk flow ceases. In conventional milking parlours, the detachers may be of the cord-type or have an arm support. Presence or absence of milk flow is sensed electronically or mechanically and when the milk flow rate drops below a certain threshold for a fixed time the milking vacuum is shut off and the teatcups fall away. The teatcups are prevented from touching the floor by a nylon cord or an arm. The same principles are used for automatic milking. Teatcups can be removed individually by means of a separate removal system by shutting off the vacuum and retracting the milk pipe into the magazine (Mottram, 1991) or in group by means of a milk rack (Hogewerf et al., 1992). Schillingman and Artmann (1990) give some examples of mechanisms to place the teatcups away from the cow and in their initial position. With automatic milking systems, it is essential that removal systems can deal with unexpected events. Therefore, Mottram et al. (1991b) developed an improved control system for automatic cluster removal by adding a measure that senses liner slip, limits the total time for milking to override flow sensor failure and prevents the recorder jar from flooding.

3.9. Exit of the cow

Once milked, the cow has to leave the milking stall. This exit can be automated by a pusher (a gate) that forces the cow out of the stall (Bottema, 1992) or by electrically charged chains which can be lowered and raised above a cow's back (Wierenga and Hopster, 1987). With both systems, the cows quickly learn to leave the box before any contact with the gate or the chains occurs. These devices can also be installed in selection units to reduce the occupation time of these units (Ketelaar-de Lauwere, 1992).

3.10. Monitoring and recording parameters for management purposes

As the milker will not be present during automatic milking, animal physiological data will have to be gathered automatically and on-line, using sensors and computer-based herd management systems. Different sensor-based systems are yet available to measure changes in health, reproduction and performance parameters and to detect and report deviations in the normal state of each cow. These systems may also be applied to automatic milking. A summary of the current technologies is given below.

Body temperature

Oestrus, some diseases and infections are accompanied by an increase in body temperature. Monitoring temperature data is therefore important to support a routine management system. Direct measurement of body temperature is possible by an ear-mounted sensor (Roth, 1987). Trials with implantable telemetric systems for measuring body temperature gave some practical problems with data reception (Metz-Stefanowska et al., 1992). Indirect measurement can be achieved by automatic measurement of the milk temperature in the milk claw or the short milk tube (Maatje and Rossing, 1976; Paul and Speckmann, 1979; Maatje et al., 1987; Schlünsen et al., 1987). Fordham et al. (1987) concluded that the short milk tube was a better place for a temperature sensor than the claw piece, because of the smaller influence of ambient temperature on the measured milk temperature.

Body temperature shows an increase 3 to 5 days prepartum, peaking about 2 days before calving, then dropping towards parturition. The occurrence of the peak temperature may be used as a management tool in alerting the herdsman (Metz et al., 1987b).

Body weight

Body weight can be used as a parameter for individual concentrates and roughage supplementation (Maltz et al., 1987; Pirkelmann et al., 1987; Artmann, 1987; Maltz et al., 1991; Maltz et al., 1992a; Maltz et al., 1992b). A decrease in body weight can signal health problems. Different locations are suitable for automatic weighing (platform) : the entrance or exit of the milking parlour, the floor of a milking stall or a concentrate feeding station (Ipema and Pluijgers, 1987).

Milk yield

Differences between recorded and expected milk yield can indicate cases of oestrus or diseases which induce decreases in milk production. Milk meters are commonly used for milk yield recording. Due to the smaller milk yields (< 10 kg) as a result of more frequent milking (Ipema and Benders, 1992), the daily milk yield of a cow will be less accurately measured when the accuracy of a milk meter is only ±200 g for a milk yield below 10 kg (ICAR, 1987). Göttsch (1990) found that only three out of six commercial milk meters succeeded to record small milk yields with acceptable accuracy and precision. The current milk yield recorders will probably need to be modified for automatic milking. Devices for the automatic collection, handling and identification of milk samples for analysis will also be required.

Automatic evaluation of milk yield and milking characteristics (e.g. milk flow rate) can be useful as a method for monitoring correct milking machine performance, but even more important as a measure of the response of the teat to the milking conditions. Information about individual quarters would be advantageous for diagnostic purposes (Butler et al., 1990; Mottram et al., 1994). To detect milk meter errors automatically, Wendl et al. (1992) developed a mathematical model that compares actual and expected milk yield. Regular observations of large differences between both can point to a milk meter error.

Cow behaviour

Cows on heat tend to be more active, to mount on other cows or await to be mounted. Oestrus is usually detected on the farm by observing behavioural changes. Mount detectors, the use of marker bulls and video surveillance are tools to support the farmer's observations but are not yet automated (Lake, 1987). Cow movements can be registered with a so-called mercury switch. Recording the number of steps during a given period indicates the activity level. Several researchers reported improved heat detection rates by using pedometers (Kiddy, 1977; Pennington et al., 1986). Heat detection rates of 75 to 90% and even more can be achieved with pedometers (Timms et al., 1991; Liu and Spahr, 1991; Pulvermacher and Wiersma, 1991; Eradus et al., 1992). Activity measurements can also be used for the detection of illness or leg and claw disorders (Maatje et al., 1987; Schlünsen et al., 1987).

Heart rate

Heart rate can be measured by means of an ear-mounted sensor. Oestrus raises the absolute pulse rate per minute and by sudden changes in heart rate the number of interruptions of the rest period at night (Schlünsen et al., 1987).

Feed and water intake

The amounts of water, concentrates and roughage intake are influenced by oestrus, disease and other factors. Changes in intake can be used to alert the farmer. The use of programmed concentrate distribution has increased greatly during recent years on dairy farms (Wierenga and van der Burg, 1988). Most available systems do not register the amount of rest portions, although it would give information about the real concentrate intake. Monitoring water intake can also be automated. An automated individual forage-feeding system with forage intake recording is already tested and appears promising for fully automated, computer-controlled dairy farming (Ipema and Rossing, 1987).

Milk composition

As changes in the content of milk constituents are usually caused by disorders of the cow, an on-line analysis of the milk composition would be a grateful tool for animal monitoring. In addition, it would assure the quality of the delivered milk to dairy factories and consumers. Protein, lactose, fat content and cell count can serve as indicators of metabolic disorders. The progesterone and luteinizing hormone level in milk (e.g. progesterone test) can signal oestrus. Suitable equipment for on-line measurements of these milk constituents are not yet available. They can only be measured off-line and by expensive, time and labour consuming laboratory methods. Koelsch et al. (1994) developed a biochemical sensor for progesterone based upon integration of an antibody-antigen reaction with a piezo-electric crystal. The concept approach seems to be promising. One issue is the extended period of exposure before a significant change in frequency can be observed. Near-infrared spectroscopy seems also to be a promising method for on-line milk quality control (Tsenkova et al., 1992; Schmilovitch et al, 1992). NIR is a non-destructive method which was found to be very reliable for mastitis diagnosis. It gives similar results as the standard method for the somatic cell count (Tsenkova, 1988). Cattaneo (1994) mentioned the realization of a simplified cytofluorimeter able to monitor automatically the number of somatic cells present in a milk sample but he did not give any details about the device.

It is well known that strong positive correlations can be found between electrical conductivity (EC) and mastitis and EC is therefore a useful method of diagnosing intramammary infections (Fernando et al. 1982; Linzell and Peaker, 1975; Schlünsen and Bauer, 1992). On-line sensors were constructed to measure quarter milk conductivity during milking (Maatje et al., 1983; Rossing et al., 1983; Yamamoto et al., 1985, Maatje et al., 1992).

3.11. Models and management systems for processing and interpretation of data

Apart from the automated monitoring systems knowledge-based systems are required for the interpretation of sensor data and to detect changes as real deviations. To achieve highly successful detection rates and a low error rate (false detections) a combination of measured values of parameters is needed. Statistical techniques (Maatje et al., 1992; Eradus et al. 1990), rule-based techniques (Maatje et al., 1987) and learning-based techniques (Nielen et al., 1991) can be applied for a combined processing of variables in a detection model for monitoring and diagnosing health and reproduction (de Mol et al., 1992). Activity, milk yield, milk temperature, quarter milk conductivity and concentrates intake are on-line gathered data suitable as input for a detection model to detect oestrus, mastitis, other infectious diseases, metabolic disorders and lameness. In addition information from a management information system (MIS) (e.g. expected milk yield, recorded oestrus dates, sickness history, etc.) can support the calculations of the detection model (de Mol et al., 1993).

4. Effects of automatic milking

4.1. Effects on milk production and milk quality

An increased milking frequency (more than 2 times a day) results in an increase in the milk yield. This has been measured under many experimental and field circumstances but usually for three times daily milking where 5 to 25% more milk was obtained (Hillerton and Winter, 1992). The increase in milk yield in AM simulation trials amounted to 8% (Rossing et al.,1985), 14% (Ipema et al., 1987), 13% (Gravert, 1988) and up to 20% (Grimm and Rabold, 1987) for respectively milking frequencies of 5.4, 3.9, 4.6 and 3.9 times per 24 h. Ipema et al. (1991) reported that a milking frequency of 6 times a day resulted in an increase in the milk yield of only 10%. From the above-mentioned results it is clear that a higher milking frequency (3 to 4 times a day) with automatic milking will increase the production level. In the context of the quota regulations it means that the same milk quantity can be produced with less cows.

The milking frequency affects the milk composition. Decreased milk fat contents at higher milking frequencies were found by Ordolff (1989), Ipema et al.(1987) and Ipema et al. (1991). In an experiment with 3 and 4 times daily milking Ipema and Benders (1992) found an increase in milk fat and protein content with respectively 10 and 11%. They suggested that this increased production was partly realised by utilising body reserves. Lower lactose content was also noted with higher milking frequencies . High milking frequencies appeared to cause a large increase in free fatty acid content of milk (Ipema et al., 1991). Jellema (1986) found that the sensitivity for lipolysis increased with short milk intervals and that lipolysis sensitivity differs among cows. Higher free fatty acid contents influence milk taste, cheese and butter making negatively and needs therefore to be avoided.

To ensure a high milk quality healthy cows with unaffected udders are essential. A trend for reduced somatic cell counts and bacterial infection with three times daily milking was indicated by Waterman et al. (1983). Ipema et al. (1987) and Kremer (1992) found similar results. In a research on the influence of milking frequency on mastitis, the rate of clinical mastitis in quarters milked 4x daily was found to be significantly lower than in quarters milked 2x daily (Hillerton, 1991). Also the rate of new infections was over 50% lower.

Microbiological quality of milk harvested by an automatic milking device will be affected by the frequency of cleaning. With conventional milking the milker starts up a cleaning and disinfection programme e.g. twice daily. A 12 hour cleaning interval is insufficient to prevent high microbial counts in an automatic milking system, although the fresh milk with bacteriostatic properties will flush away residues from previous milkings (Verheij, 1992). With automatic milking the cleaning frequency and programme have to be modified due to the irregular milkings (voluntary visits) spread throughout the day. The number of cleanings has to be limited with regard to AMS capacity, but must be satisfactory with regard to milk quality. In addition, the consumption of water, chemicals and energy has to be taken in consideration.

Rinsing the milking installation with 10 l of clear water is sufficient to remove nearly 100% of the milk residues (Runnalls, 1988). In an experiment to simulate fully automatic milking the installation was cleaned twice daily and rinsed four times with 10 l of lukewarm water. The identical bacterial count of experiment and reference group, showed that this cleaning was adequate (Ipema et al., 1987). Ordolff and Bölling (1992) reported that milk residues left in the milking equipment after milking for up to 60 minutes do not increase bacterial count. If milking intervals exceed this time a rinsing with water or full cleaning and disinfection may be necessary to guarantee milk quality.

4.2. Effects on animal health and welfare

Optimal biological functioning of an organism occurs only when it lives in the most appropriate surroundings (Humik, 1992). Therefore the basic biological requirements of animals should be respected in the design of automatic milking systems.

Udder health might be affected by an increased frequency of milking. Hillerton and Winter (1992) found that the rate of clinical mastitis and of new infections was lower in udder quarters milked 4 x daily than in quarters milked 2 x daily. Waterman et al.(1983), Allen et al. (1986) and Gisi et al. (1986) reported that udder health was not affected by 3 x daily milking. More frequent milking could lead to more frequent opening of the teat duct and to more frequent invasion of bacteria. The risk of cross-infections through the milking machines and due to the lower number of milking units might be 50% higher with automatic milking (Elliot, 1961; Pearson et al., 1979). On the contrary, more frequent milking might improve teat hygiene as there will be more frequent cleaning. More frequent milking increases the duration of machine milking which causes a significant increase in the number of teat end erosions and eruptions. The results suggest that more attention should be paid to the milking techniques applied with automatic milking in order to minimize physical stress on the udder and teat tissues (Ipema and Benders, 1992). More research in this field is necessary. The experiments conducted so far suggest that more frequent milking could improve udder health and bring improved welfare.

Few studies have investigated the effects of milking frequency on reproduction. Reproductive performance measured as days to first oestrus, days open, or services per conception was not influenced by a milking frequency of three times daily (Amos et al., 1985). DePeters et al. (1985) reported a reduced reproductive performance of cows milked 3x a day than of cows milked 2x a day. Allen et al. found that cows milked three times a day had fewer days to first breeding than the cows milked twice a day and noted that 3 x milking may be advantageous.

Complete automation of milking may involve keeping dairy cows indoors for longer periods or throughout the year. With zerograzing cows, dermatitis digitalis, hyperplasia interdigitalis, white line process and severe lesions are more prevalent than with grazing cows, but dermatitis interdigitalis is less prevalent. White line separation, sole ulcer and phlegmona interdigitalis occurs on zerograzing farms as much as on dairy farms with grazing cows during the summer (Smits et al., 1992). In a research on the influence of intensively managed rotational grazing, traditional continuous grazing and confinement housing (zerograzing), no udder health differences were observed among grazing treatments. However, the highest milk quality in terms of standard plate count and bacterial count was found in herds using rotational grazing (Goldberg et al., 1992).

Behavioural studies of Ipema et al. (1988; 1991) showed that cows spent more time lying in the cubicles and less time standing with high frequent milking. A lower tension in the udder which offers more comfort to the cow to lie down might explain the increased lying times. High frequent milking will fit the natural pattern better when a comparison is made with the frequency of suckling in beef herds (4 to 6 times per 24 h) (Day et al., 1987).

Through the integration of sensors in the AMS with on-line data acquisition of different health, reproduction and milk parameters, monitoring of cows is done more consistently, faster and continuously in comparison with human observations. Earlier detection and treatment of deviations might improve animal health and welfare. Thanks to automation the herdsman will probably have more time to follow up carefully individual cow performances. In addition, milking and feeding decisions with automatic milking can be taken on-line and according to a cow's individual pattern.

Less interaction between a herdsman and his animals can have positive and negative consequences. Seabrook (1991) found a relation between the cow's stress level and milk yield and the personality of the milker. An introvert milker appears more suitable for successful milking. Less interaction between cows and herdsman can lower animal stress and improve milk production and animal health. Interaction between cows and moving components of the AMS may also cause stress to the cow. Through habituation cows may overcome fear of aversive situations and handling procedures. Hurnik (1992), Metz and Ipema (1993) stressed that ethological considerations should be included with the development of the AMS not only to reduce stress and to better the well-being of the cows, but also to assure the repetition of the cows' voluntary visits to the AMS.

From the above-mentioned literature survey we conclude that automatic milking will have positive and negative effects on the health and welfare of the cows. Negative effects such as teat damage (due to the higher duration of machine milking) and stress require further research on respectively milk technical aspects and behavioural aspects. The overall impression is however that automatic milking based on an individual cow approach will improve the health and welfare of the animals.

4.3. Environmental effects

In The Netherlands as well as in other countries intensive dairy farming gets in conflict with governmental regulations on ammonia emissions, overproduction of manure, overmanuring, fertilizing limits and water protection. As a result of the increase in milk production with 10 to 15%, by a raised frequency of milking (3-4 times a day), less cows can be held to attain the same milk quota on a farm and less animal waste would be produced. The lower quantity of forage required will result in a surplus of forage. This surplus can be avoided by a reduction in nitrogen fertilising. A combination of a reduction in nitrogen fertilising and a raise in milk production can result in a considerable reduction in ammonia emission and nitrate leaching (Mandersloot, 1992). Zerograzing combined with automatic milking will positively influence the environment, thanks to the lower nitrate leaching and the possibility to distribute fertilizers on the right place and at the right moment. A reduction in ammonia emission from the cow house is with zerograzing only possible if some precautions are taken (e.g. manure scraper).

More research is needed on wastewater production from automatic milking systems as water will be used for cleaning the milk installation and the milking parlour.

4.4. Socio-economic effects

The effects on the social life of the farmer's family, both at the farm and outside, will depend on the intentions of the farm manager with the purchase of an AMS. The milking robot can be applied only to replace the milker in a conventional milking parlour. In this case the farmer will still be tied to fixed milking times and will still have to work at unsocial hours of the day but labour requirement for milking will probably be lower. When a fully automatic milking concept is successfully applied, the expectation is that milking stops to be a stringent limitation of the farmer's activities. A less restrictive social and family life comparable with that of other families will then be possible. The state of being tied down to his farm will depend on the reliability of the system. Data about the reliability and performance of an AMS on commercial farms are not available yet. Irregular interventions for repair cause interruptions in the daily labour organisation and the family activities but also stress to the farmer and consequently to family life.

With fully automatic milking one expects a remarkable reduction in labour requirement. The available labour can now be used to increase the milk quota or to buy and cultivate more farmland. In an economic study, Harsh et al. (1992) found that reducing the herd size is a better alternative than purchasing milk quota. In addition, the purchase of quota by more competitive farms will decrease the total number of dairy farms at a higher rate than before. Farms will become larger.

The purchase of an AMS involves a high investment which may cause a higher mental load on the farmer, especially if the farm is already heavily in debt. The break-even investment level for an AMS in comparison with a double eight herringbone milking parlour, is NLG 310 000 for The Netherlands (Harsh et al., 1992). If the investment in an AMS is below this amount, it would be economically advantageous to invest in the AMS. In the U.S.A. it seems unlikely that the capital intensive AMS will soon be a viable alternative to large scale milking systems, due to the low labour costs there (Armstrong et al., 1992). An Italian study indicates that the application of the AMS in the Italian situation requires a milk production increase of 30% which is not realistic nor feasible. The introduction of a milking robot in a standard tandem parlour offers more perspectives (Sangiorgi and Provolo, 1992). All these economic studies are based on several assumptions which are still not proven. They give some indications about possible economic effects.

On large dairy farms with one or more hired workers labour is more flexible than on family farms. The use of an AMS can cut down on hired labour on large dairy farms and decrease the employment on farms. On the other hand, new jobs can be created in the manufacturing industry, e.g. the constructors of automatic milking installations, robots, etc. Dairy farming will become more capital intensive, making it more difficult for new and young farmers to start a dairy farm. Once introduced, the AMS may contribute to a more sustainable dairy farming.

At the moment it is not clear how the consumer will react on 'robotic milk'. Milk produced under more hygienic, more animal friendly and less polluting conditions might be a reason for some consumer groups to prefer robotic milk above conventionally produced milk. Then consumers have to be well informed.

4.5. Effects on labour aspects

The use of an AMS will have consequences on labour organisation, labour conditions, labour supply and on their mutual relations. The effects on labour organisation are discussed in the following chapters. In an AMS, the operations that need to be performed and the environment in which will be worked will change thoroughly. Labour conditions will be affected. The time pressure, the high frequency of short-time work elements (monotonous) and the high concentration required make conventional milking a job of medium to high mental load (Belt, 1984). The collection of individual cow data during milking, is a demanding activity when it is not automated (Belt and Zegers, 1984). The implementation of an AMS can solve these problems. On-line registration with sensors and computer processing of the data can support the farmer. A clear presentation of essential information to the farmer is very important in this connection. A reliable, failure-free system and a specialised support at any moment of the day (or night) are necessary to assure positive effects of the AMS in relation to mental load.

The high number of neck, back and shoulder complaints with dairy farmers in a research of Hildebrandt (1989) confirms the high physical load of the farmer during milking. Lundqvist et al. (1993) stressed the fact that the milker has to stand for extended periods during milking and in high body loading positions during 10% of the milking time. Moilanen and Taattola (1992) mentioned the occurrence of unfavourable and back loading attitudes during milking in a milking parlour. Since the milking robot will take over all physical work of milking, the above-mentioned problems will be solved. Only when teatcups have to be attached manually or repair and maintenance operations have to be done, physical efforts of the milker are still needed. Although the manual operations are to be minimized, attention should be paid to the attainability of some work points (e.g. the cow's udder) in the design of an AMS.

As physical work will be less, physical affections of the locomotive system will be reduced with automatic milking. The incidence of labour unfitness caused by physical activities related to milking will be rare. The AMS can even replace a farmer with (unexpected) physical limitations.

Physical environmental elements such as light, noise and climate are rather unfavourable in a conventional milking parlour. As the farmer will be less hours in this unfavourable environment with automatic milking the AMS can contribute to the health of the farmer. If the AMS is installed in the cows exercise area high concentrations of ammonia, organic and inorganic dust are possible. A separate area for the AMS is recommended to minimize adverse environmental conditions.

Milking in a conventional milking parlour is not without risks according to statistics on accidents. Lundqvist (1992) reported that one-fourth of the occupational accidents in Swedish agriculture occurred in connection with milking and handling of animals within the farm buildings. Positive effects can be expected with the AMS as there will be less contact with animals. On the contrary, less socialized animals may become fearful and react in a negative and unexpected manner when exposed to humans (Gross and Siegel, 1993).

Sonck (1992) and Lundqvist (1992) pointed to the safety problems with milking robots. If the milker enters the robot-movement zone, accidents may occur. However, the speed of the robot and the forces executed by the robot arm (of the Prolion milking robot) are so low that the risk of injury is limited. Outside the robot-movement zone, exposure to mechanical or electrical energy can create a safety hazard. Nevertheless a rigorous protection of the lower parts of the system is also necessary with respect to the aggressive environment in which the system has to operate. At present, no data are available about the safety risks of automatic milking robots. A systematic analysis of these risks should be carried out to give advice for future AMS design.

5. Conclusions

Technical solutions for the automation of each milking activity performed in conventional milking parlours are available today. However the developed devices do not always attain the same degree of accuracy as the milker does in his work. When cleaning is carried out manually it can be assumed that the operator will ensure that cows are clean prior to milking. Determining the cleanliness of the cow's teats is still an aspect of milking which needs further research. No current automatic attachment system guarantees a 100% successful attachment of the teatcups. Too slow and inaccurate systems, inaccessible teat positions and difficulties with the exact location of the teat positions are problems that still have to be solved. However, much progress has been made during the last years and attachment scores of 85 to 99% have been reached.

As some cows in a herd might show a low frequent visiting pattern to the selection unit or milking unit, only an attachment score close to 100% is acceptable. Behavioural studies have shown that cows are able to use the AMS voluntarily and that they become accustomed to it. The problem of 'fetching cows' might be solved in some way by rewarding them with concentrates, but not earlier than in the selection stall (Metz-Stefanowska et al., 1992). So far, no research has been carried out on the voluntary visits of cows to an AMS if cows are grazing and have to walk up to a few hundred metres. Heifers or cows confronted for the first time with the AMS will have to be trained to use the AMS (Ketelaar-de Lauwere, 1992).

More research is needed on the integration of the AMS in new and existing loose housing systems. The experiences with the layout of AMS cowhouses are limited to experimental farms. Pirkelmann and Bauer (1994) proposed layouts of cubicle loose houses with two and three rows of cubicles. In each layout, the AMS was located centrally in the cowhouse and gave access to the feeding table. These proposed layouts are not yet investigated.

Activity, milk yield, milk temperature, quarter milk conductivity and concentrates are data that can be gathered on-line and that are suitable for detection of oestrus, mastitis, infectious diseases, metabolic disorders and lameness. Management information systems which translate these data into essential information that is clear, easy and quickly readable and comprehensible for the farmer, need to be developed for automatic milking systems and have to be tested in practice.

An increased milking frequency based on voluntary visits of the cows to a milking point will raise the milk yield by 5 to 25% and will positively affect the animals' health and welfare. Negative effects such as teat damage, due to a higher duration of machine milking, and stress require further research on respectively milk technical aspects and behavioural aspects. With regard to the contradictory results of the effects of milking frequency on reproduction, as found in literature, this issue requires more attention in future research.

The prospects on environmental effects are in general positive. However, wastewater production with an automatic milking system needs to be compared with that of conventional milking parlours.

Socio-economic effects as well as effects on labour aspects will depend largely on the reliability of the automatic milking system. However, the expectation is that automatic milking will free the farmer from the daily obligation of milking, that labour requirement will be reduced and labour conditions will improve. Automatic milking implies the use of a robot which can create safety risks, due to the exposure of the farmer to mechanical and electrical energy. A systematic analysis of these risks should be carried out in combination with ergonomic research in order to give advice for future AMS design.

One of the main advantages that automatic milking might offer is the expected labour saving. Few and rough estimations on the expected labour saving with automatic milking were found in the literature. The following chapters deal in more detail with the effects of automatic milking on labour and labour organisation on dairy farms. The above-described state-of-the-art may refer to the technical conditions in which the research is carried out. The research topics of the following chapters are described in chapter 1.

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Chapter 3

The milking capacity of a milking robot

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Abstract

The automatic milking process is represented by means of a model which allows the factors affecting the capacity of an automatic milking system to be studied. The main factors investigated are the times required for cow movements, milking processes and robot motions. With one robot serving two stalls, the idle time of the robot arm was 54%. From an analysis of the milking cycle, it is shown that the robot arm can serve up to four milking stalls in-line. The model showed also that the capacity of an AMS arrangement with two stalls in-line, can be increased from 11.7 to nearly 15.4 cows/h by increasing the robot speed, by executing some milking processes simultaneously and by changing the sequence of milking processes. If the robot is available for milking for 20 h, 308 milkings could be carried out. Thus, with a milking frequency of four milkings per cow per 24 h for the whole herd, the milking robot could serve nearly 80 cows. The possibilities of alternative arrangements such as a double tandem and a rotary tandem milking parlour, are also tested with the model.

Key words : milking robot, capacity, automatic milking

Notation

AMS	automatic milking system
$c_{1,2,3,4,5}$	constants
CDC	cycle duration of the cow, min
CDR	cycle duration of the robot arm, min
CST	operational time to clean and stimulate the teats, min
d	distance between two sequential rest positions of the robot wagon (equal to the length of a milking stall), m
$d_{max,\ n}$	average distance of the largest robot movements of all possible sequences of serving n milking stalls, m
EBC	operational time to close the entrance door of the milking box and to trap the cow in the box, min
EBO	operational time to open the entrance door of the milking box, min
ENT	time that the cow requires to enter the milking box until the moment of cow identification, min
EPO	operational time to open the entrance door of the milking parlour, min
EXO	time to open and close the exit door of the milking box accumulated with the time that the cow requires to leave the box, min
IC	idle time of the cow, min
INT	maximum time interval between entrance of the cow in the milking stall and the attachment of the teatcups, min. Sum of IC, MRD, RMS_{max} ,RMR, RST and RAT
IR	idle time of the robot arm, min
MAC	operational time to adjust the position of the manger in the milking stall conformable to the body length of the cow, min
MMA	operational time to move the manger until the maximum length of the milking box (2.40 m) is reached, min
MMI	operational time to move the manger until the minimum length of the milking box (2.13 m) is reached, min
MMT_{av}	average machine milking time of all the cows, min
MRD	operational time to lower the milk rack to its standard position, min
n	number of milking stalls
RAT	operational time to attach the teatcups to the udder, min
REM	operational time to remove the milking teatcups and to return the milk rack arm, min
RET	operational time for the robot arm to return to its initial position after the attachment of teatcups, min
RMR	operational time for the robot arm to move downwards to take the milk rack, min
RMS_{av}	operational time for the average movement of the robot arm from one milking stall to another, assuming a random sequence of serving the milking stalls, min
RMS_{max}	operational time for a robot movement of a distance $d_{max,\ n}$, min
RST	operational time to search for the reference teat and the remaining teats, using the sensors of the robot arm, min
v_c	speed of movement of a cow, m/min
v_r	speed of the robot wagon, m/min
WAS	time that the cow requires to walk through the sidepassage of the milking parlour before and after milking, min

1. Introduction

Work performed at the experimental farm of the DLO Institute of Agricultural and Environmental Engineering has indicated that the automatic milking system is nearly ready for introduction on commercial farms. Hogewerf et al. (1992) stated that the success rate, being the number of attachments of four teatcups which were successful, was 88.5% and that a further increase of this figure can be expected. This technical innovation in animal husbandry offers higher milk yield (e.g., a 14% increase when milking three times/d), better prospects for the welfare of individual cows and for labour productivity and reduces workload on family farms (Ipema and Benders, 1992; Sonck, 1992).

Automatic milking systems (AMS), as reviewed by Bottema (1992), have already been installed on commercial farms. These are total systems in which the entire milking process is supposed to be automatic. However, a system supervisor, who assembles the herd in a collecting yard before milking, starts the system and for the remaining time he has only a supervisory function. Herdspersons who insist on keeping their cows on pasture during the summer, will have to follow this working method. The capacity of the AMS is very important in this context, as it determines the time the milker has to control the milking process. Of course, fully automatic milking, based on voluntary visits of cows to selection unit(s) and an accompanying control and management system, is the final object of robotic milking (Devir, 1992). But even then, the maximum capacity of the AMS is important because the profitability depends on the relationship between price and capacity and on occupancy (Kuipers and Van Scheppingen, 1992).

The question remains how to define the capacity of a milking robot. The capacity is often expressed in number of milkings per day but this should be considered in relation to the configuration of the AMS, that is the number of milking stalls, the use of selection gates, milking frequency, herd size, etc. Comparing these capacities is not really opportune. To derive the capacity of a milking robot, a general model of the robotic milking process is needed. All milking systems have a number of common factors : a cow enters a milking stall to be milked; the robot executes a number of dairying tasks, and when the cow has been milked, it leaves the stall to rejoin the herd (Gouws, 1993).

Genety (1981), Hop (1989), Sonck et al. (1991) and Lengyel (1993), made theoretical studies and described methods to calculate the performance of traditional milking parlours on the basis of formulae. In this study we discuss a simple model which expresses the interaction between cow and robot during the milking process. The object was to devise a model to calculate the capacity of a milking robot during full operation that is independent of the way the cow is presented to the AMS and subsequently to obtain a clear insight into the different phases that determine the milking robot capacity and the consequences of altering process motions, process times, and the sequence of operations. Sangiorgi and Provolo (1992) devised a model to assess the performances of a robot working in a standard tandem parlour. In our study, the model is based on the milking process with a two-stall milking robot as it performs now on commercial farms (Bottema, 1992). Based on the model, the performance of the milking robot and of alternative milking processes are calculated using observations made in practice. The possibilities of a double tandem and a rotary tandem milking parlour combined with a milking robot are also shown in this study. These AMS arrangements are shown in Fig. 1B and Fig. 1C respectively.

2. Model of the milking process

Woerlee (1991) distinguishes three phases in modelling scheduling problems. The first phase involves the construction of the production system. The second phase concerns the specification of job activities (i.e., how a job uses the machines and buffers in a production system). The third phase determines the relationship between the individual job activities. Following this procedure, we built a model of the robotized milking process.

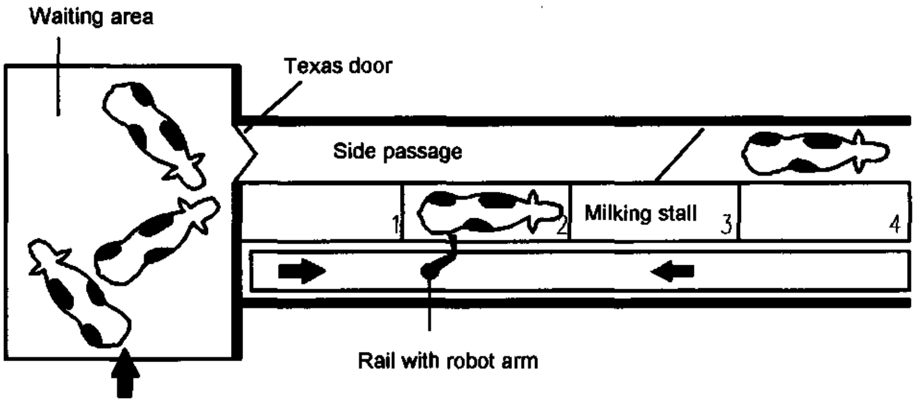
To calculate the capacity of the AMS during full operation, we assume that the cows enter the milking parlour consecutively and without delay as soon as a milking stall becomes free. Fig. 1A shows a layout of a fictitious AMS with n stalls in-line. The waiting area, situated in the cubicle house, is separated from the milking parlour by an entrance door. The operation of this Texas door and of the doors of the milking stalls is controlled by the computer, which is comparable with the situation in an open milking parlour. The robot, equipped with sensors for locating the teats, moves on a rail along the milking stalls and the robot arm takes up the milk rack with the four teatcups. When the sensor has scanned the teats, the teatcups are put on the udder in a certain order. A detailed description of the teatcup attachment is given by Hogewerf et al. (1992). It is important that the robot arm is disconnected from the milking rack when all the teatcups are attached. Then it moves back to its initial position ready to serve other milking stalls.

In this study, we assume that the robot wagon on which the robot arm is installed, remains at the last served milking stall and moves to a subsequent milking stall as soon as the cow has entered the box, the feeder box has been adjusted at the right distance, the entrance door of the box has closed, and the milk rack has been moved into its initial position. In the practical two-stall AMS arangement, the robot wagon moves to a rest position (centrally situated between the two milking stalls) after serving a cow.

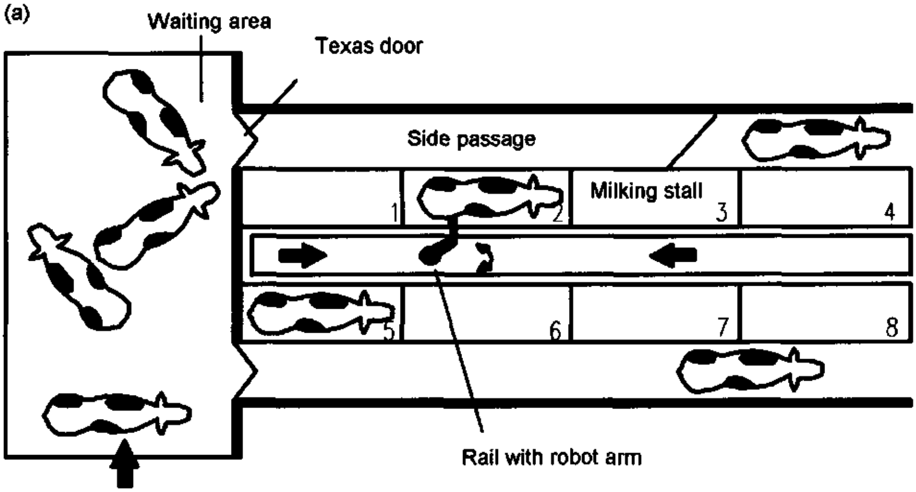
To optimize the milking process in a situation as shown in Fig. 1A, the different components of the process have to be coordinated. The robot arm has to do several jobs for each cow that enters a milking stall but jobs can be carried out only in a fixed sequence. Some jobs cannot be carried out by the machine if preceding jobs or activities (e.g., of the cow) have not been fulfilled. In addition, the robot arm has to serve one or more milking stalls. Lack of coordination induces passive periods for one (or both) components. This means that the robot arm has to wait until a milking stall becomes free or that the cow waits in a milking stall until the robot arm can serve it.

The robot arm and cow also experience a 'returning' process. The cows voluntarily enter the milking parlour, enter and leave the milking box, and return to the loose house. Each cow passes through the following steps in sequence (the symbols of the corresponding operational times are given between brackets).

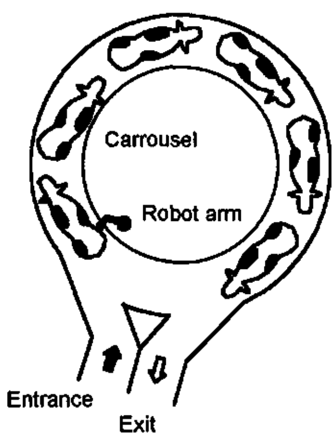
(a) *Starting activities of the cow.* As soon as the entrance door of the milking parlour opens, the cow walks through a sidepassage to enter a free milking stall. After milking, the cow leaves the



(a)



(b)



(c)

Fig. 1. *Automatic milking system arrangements : (a) AMS with n milking stalls in-line or single tandem AMS arrangement; (b) Double tandem AMS arrangement; (c) Rotary tandem AMS arrangement*

parlour through this sidepassage. Apart from entering and leaving the milking box, the distance travelled by each cow is equal to the length of the sidepassage. The activity time that the cow needs to walk through the sidepassage can be written as follows :

$$WAS = \frac{nd}{v_c} \tag{1}$$

where n is the number of milking stalls, d is the length of a milking stall and v_c is the speed of movement of a cow. When the cow enters the milking stall, it is identified (ENT). The length of the box in the milking stall is determined by the position of the manger of the automatic concentrates dispenser, installed in the stall. When the cow enters, the length of the box is only 2.13 m, due to the position of the manger. As soon as the cow is identified, the manger moves in a horizontal direction, until the length of the box is conformable to the body length of the cow (which is stored in the computer) (MAC). The maximum length of the box is 2.40 m. After this adjustment, the entrance door of the milking stall closes (EBC).

(b) *Preliminary milking time.* The milk rack moves downwards to its standard position as soon as the robot arm is free to serve the particular milking stall (MRD). The cow has to wait for the robot arm to move to the milking stall. We assume that all milking stalls are served in one cycle of the robot. The largest robot movement in a robot cycle will delay the processes in the subsequent cow cycles and will therefore determine the cow cycle duration. The average distance ($d_{max,n}$) of the largest robot movements of all possible sequences of serving the milking stalls are calculated for AMS arrangements with 1 to 10 stalls and by drawing randomly 10 times 100 000 sequences of serving with a simulation program. Table 1 shows the average values of the 10 runs. The 95% confidence interval of $d_{max,n}$ is for all cases smaller a 0.005 d. The operational time for the average distance of the largest robot movements is :

$$RMS_{max} = \frac{d_{max,n}}{v_r} \tag{2}$$

where $d_{max,n}$ is the average distance of the largest robot movements of all possible sequences with n milking stalls and v_r is the speed of the robot wagon.

Table 1. *The average ($d_{max,n}$) of the largest robot movements of all possible sequences of serving n milking stalls in-line with a distance d between two sequential rest positions of the robot*

n	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
$d_{max,n}$	0d	1d	2d	2.667d	3.417d	4.217d	5.033d	5.864d	6.707d	7.562d

After its arrival, the robot arm moves downwards to take up the milk rack (RMR). The sensors search for the first (reference) teat and the remaining teats (RST). Subsequently, the teatcups are attached to the udder (RAT).

(c) *Milking time.* A cleaning device sprays water at four places on the head of each teatcup liner. During this time a high pulsation rate is used. The idea is that the water and the movement of the liner together clean and stimulate the teats (Schuiling, 1992) (CST). As soon as milking starts, 1 kg of concentrates is supplemented at a rate of 0.3 kg/min. The average machine milking time of all the cows is used in the model as machine milking time (MMT_{av}).

(d) *Post-milking activities.* The teatcups and the milk rack are removed and returned (REM). Then, the manger moves until the maximum length of the box is reached, i.e. 2.40 m (MMA). The exit door of the milking box opens, the cow leaves the box, and the exit door of the box closes (EXO). The manger moves back to minimize the box to a length of 2.13 m (MMI). Further, the entrance door of the box (EBO) and of the milking parlour open successively (EPO).

The total cycle duration of the cow (CDC) can be expressed as the following accumulation of activity times :

$$CDC = \frac{nd}{v_c} + ENT + MAC + EBC + MRD + \frac{d_{max,n}}{v_r} + RMR + RST + RAT + CST + MMT_{av} + REM + MMA + EXO + MMI + EBO + EPO \quad (3)$$

In Eqn. (3), the operational times EBC, MRD, RMR, CST, REM, EBO and EPO can be considered as constants or fixed times. If all cows have approximately the same body length, the operational times of MMI, MMA and MAC can also be considered as fixed times. As the cows are forced (by a mechanical pusher) to leave the milking stall, the operational time EXO is accepted as a fixed time.

The operational times WAS, ENT and MMT_{av} depend on individual cows. The element RMS_{max} is a function of the robot wagon speed, the travelling distance between the milking stalls and the number of milking stalls. The search process and the attachment (RST and RAT) also depend on characteristics of the cows and the robot.

The robot arm carries out the following tasks in sequence.

(a) *Movements of the robot arm.* When the robot becomes free to serve a particular milking stall, the milk rack moves downwards to its standard position (MRD). Then, the robot arm moves from one milking stall to another. Assuming a random sequence of serving the stalls, it can be shown that the average robot movement is (n+1)d/3 and the operational time therefore can be written as follows :

$$RMS_{av} = \frac{(n+1)d}{3v_r} \quad (4)$$

where n is the number of milking stalls, d is the distance from one milking stall to another and v_r is the speed of the robot wagon along the rail. After its arrival, the robot arm moves downwards to take the milk rack (RMR).

(b) *Search activities.* The robot arm connects with the milk rack; sensors search for the reference teat and subsequently for the remaining teats (RST). The teatcups are attached to the udder (RAT) and the robot arm is returned to its initial position (RET).

The robot arm has completed the total cycle if it has performed all job activities once for all the n milking stalls. The cycle duration of the milking robot arm is equal to :

$$CDR = n\left(MRD + \frac{(n+1)d}{3v_r} + RMR + RST + RAT + RET \right) \quad (5)$$

where MRD, RMR, RET are fixed times and RST, RAT depend on the cows and the robot.

To deduce in which cycle, the robot or the cow cycle, idle time occurs, it is necessary to calculate both cycle durations using Eqns (3) and (5). Three cases can be distinguished.

$$
\begin{aligned}
&\text{If } CDC > CDR, \text{ then } IR = CDC - CDR \text{ and } IC = 0\\
&\text{If } CDC < CDR, \text{ then } IC = CDR - CDC \text{ and } IR = 0\\
&\text{If } CDC = CDR, \text{ then both } IR \text{ and } IC = 0
\end{aligned}
\tag{6}
$$

Here CDR is the cycle duration of the robot arm, CDC is the cycle duration of the cow, IR is the idle time of the robot arm, and IC is the idle time of the cow. For optimum coordination between the robot arm and the cow, the robot and the cow cycle have to be equal and the idle time of the cow and robot have both to be zero (IC = IR = 0). The relation between the two cycles can be deduced from Eqns (3) and (5) :

Once the longest cycle is known, the capacity of the milking robot expressed in number of cows per hour, can be calculated. The capacity is the lesser of :

$$\frac{60n}{CDC} \wedge \frac{60n}{CDR} \tag{7}$$

The maximum time interval between the entrance of the cow in the milking box (EBC) and the attachment of the teatcups (RAT) is used to judge the quality of the milking process. This time interval (INT) is the sum of IC, MRD, RMS_{max}, RMR, RST and RAT. It is physiologically necessary that the teatcups are put on the udder as soon as possible or at least that the cow does not have to wait in the milking stall much more than 2 min. Oxytocin reaches the myoepithelium of the alveoli and the secretory ducts of the udder 0.5 to 1 min after release from the pituitary gland and causes the myoepithelium to contract. Walser (1966) and Isaksson et al. (1992) showed that this effect usually persists no longer than 7 to 10 min. We conclude that the maximum time interval INT should not exceed much more than 2 min.

3. Calculations made with the model

The following calculations are based on fixed times. Average process times for the cows and robot are derived from time studies in practice and are shown in Table 2. We found an average scanning and attachment time of 1.25 min for two attempts which was used in the model. Hogewerf (1992) mentioned an average time of 1.20 min for two attempts, which is comparable. Variability in the attachment of teatcups to different cows was not considered in the model. The robot wagon moves from milking stall to milking stall with a speed (v_r) of approximately 6 m/min. This speed is used in all calculations. In practice the robot wagon stops at a rest place centrally situated between the two stalls during idle times. However, it is assumed in the model that the robot wagon waits at the last served milking stall when idle time occurs. The distance d between two sequential milking stalls is 3 m. We noted an average speed of 15 m/min when cows move voluntarily through the sidepassage of the milking parlour.

A milking frequency of twice per day is assumed. We can deduce the MMT_{av} from a study of Ipema and Benders (1992). For a group of cows that have been milked twice a day, the MMT_{av}

***Table 2.** Actions* of the robot and cow and their respective average times*

Robot			Cow		
Action	*Time, min*	*S.D.**, min*	*Action*	*Time, min*	*S.D., min*
MRD	0.13	0.02	WAS	f(d,n,v_c)	-
RMS_{av}	f(d,n,v_r)	-	ENT	0.10	0.03
RMR	0.20	0.03	MAC	0.10	0.02
RST+RAT	1.25	0.55	EBC	0.07	0.02
RET	0.30	0.02	MRD	0.13	0.02
			RMS_{max}	f(d,n,v_r)	-
			RMR	0.20	0.03
			RST+RAT	1.25	0.55
			CST	0.15	-
			MMT_{av}	f(cow and milking freq.)	
			REM	0.20	0.02
			MMA	0.15	0.04
			EXO	0.25	0.04
			MMI	0.15	0.04
			EBO	0.05	0.02
			EPO	0.05	0.01

* The symbols of the actions are described in Section 2 and in the notation
** S.D. = standard deviation

varied from 15.9 min/d (1 to 12 weeks in lactation) to 11.1 min/d (36 to 42 weeks in lactation). In this study we assumed MMT_{av} was 13 min/d or 6.5 min per milking.

Thus for d = 3.0 m, v_c = 15 m/min, n = 2 milking stalls and v_r = 6 m/min and using Eqns (3), (5), (6) and (7), the following results are obtained : CDR = 4.76 min, CDC = 10.25 min, capacity = 11.7 cows/h, IR = 5.49 min and IC = 0 min. In this case 2.08 min is the interval time between cow entrance in the milking stall and teatcup attachment (INT), which is acceptable. The robot has an idle time of 5.49 min. In fact, the robot arm is able to serve more than two milking stalls with the above process times. With the motion times of Table 2, the cycle durations and the capacity for n varying from 1 to 10 have been calculated and are shown in Table 3. It appears that an equilibrium between the activities of the cow and of the robot has been reached between four and five milking stalls. In the case with four milking stalls the robot arm has an idle time of 0.63 min. In the robot arrangement with five milking stalls in-line the cow has an idle time of 2.34 min. If the number of milking stalls is increased ($\geq$ 5), the robot arm becomes the limiting factor. The robot arm is not able to serve all the animals in time and as a consequence the capacity of the AMS decreases.

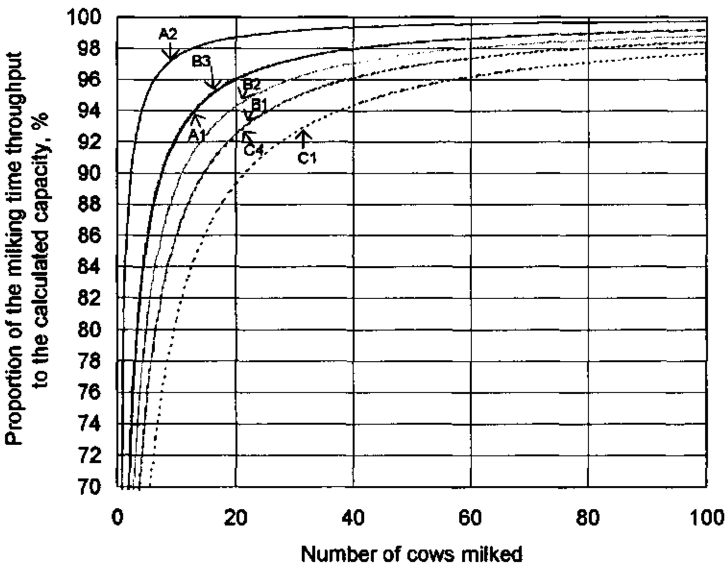
Table 3. Cycle durations and idle times of the milking process and the milking capacity with an AMS arrangement with n stalls in-line (n = 1 to 10)

No. of stalls	Cycle duration, robot, min	Cycle duration, cow, min	Idle time, robot, min	Idle time, cow, min	Milking capacity, cows/h
1	1.88	9.55	7.67	0.00	6.4
2	4.76	10.25	5.49	0.00	11.7
3	7.64	10.95	3.31	0.00	16.4
4	10.85	11.48	0.63	0.00	20.9
5	14.40	12.06	0.00	2.34	20.8
6	18.28	12.66	0.00	5.62	19.7
7	22.49	13.27	0.00	9.23	18.7
8	27.04	13.88	0.00	13.16	17.8
9	31.92	14.50	0.00	17.42	16.9
10	37.13	15.13	0.00	22.00	16.2

4. Verification of the model

Milking time throughput, defined as the number of cows milked divided by the elapsed milking session time, will differ from the capacity calculated using the model. The duration of the first and last cycles of a milking will differ from these in between because the milking stalls are not all utilized during the first and last cycles. Therefore, these cycles will increase the total milking time and consequently result in a lower figure for the milking time throughput than for the capacity calculated with the formula. Appendix A illustrates this difference by means of a simulation of milking in an AMS with 4 stalls in-line and 20 cows. The proportion, in %, of the milking time throughput to the capacity calculated with the formula is shown in Fig. 2. The parameters are as in Table 2. The difference between the results of both capacity definitions becomes smaller for larger numbers of milked cows, for a lower number of milking stalls and for complete last cycles (lines A2, B3 and C4 in Fig. 2). When the cows are presented in small groups to the AMS the maximum capacity will not be reached. The first and last cycles and the availability of only one robot arm for more than one milking stall cause a capacity reduction.

It has already been mentioned that in practice some parameters (e.g., the time that the cow needs to enter the milking stall, the attachment time, etc.) will vary from cycle to cycle and from cow to cow. In order to validate the formula, the durations of complete cycles were recorded during six milkings on a commercial farm with a two-stall AMS and 52 cows. The cows were assembled in a collecting yard before milking and entered the AMS consecutively. Due to the first and last cycles of each milking session and to operational disturbances only 274 of the 312 cycles (52 cows and 6 milkings) were accepted for the validation. The AMS computer stored automatically the following data : date, cow number, actual time of cow identification, actual time that the robot arm takes up the milk rack



Line	*No of stalls (n)*	*No of cows in last cycle*
A1 (full)	*2*	*1*
A2 (full)	*2*	*2*
B1 (grey)	*3*	*1*
B2 (grey)	*3*	*2*
B3 (grey)	*3*	*3*
C1 (dotted)	*4*	*1*
C4 (dotted)	*4*	*4*

Fig. 2. *The proportion, in %, of the milking-time throughput to the capacity calculated with the formula*

and actual time when the exit door of the stall opens (at the end of milking a cow), the number of attempts of teatcup attachment, the milk yield and real machine milking time. The cycle durations were derived from the time interval between two successive cow identifications in the same milking stall (i.e. measured capacities). Using the times presented in Table 2 and the real machine milking time of each cow, we predicted the capacity for each cow cycle on the basis of Eqn. (7) (i.e. predicted capacities). Fig. 3 shows that measured and predicted capacities agree well. A statistical analysis results in an average difference of 8% and a correlation coefficient of 0.89 for 274 measurements.

Table 4 shows the measured and predicted milking capacities of the AMS based on total milkings (considering all the cow cycles) and the absolute and relative differences between both. The predicted capacities are based on the average machine milking time of the herd. The average difference in capacity amounts to 2.2% which confirms the validity of the formula for predicting AMS capacity under continuous occupation. AMS arrangements with more than 2 milking stalls are not in use at the moment, so the formula could not be validated for these cases.

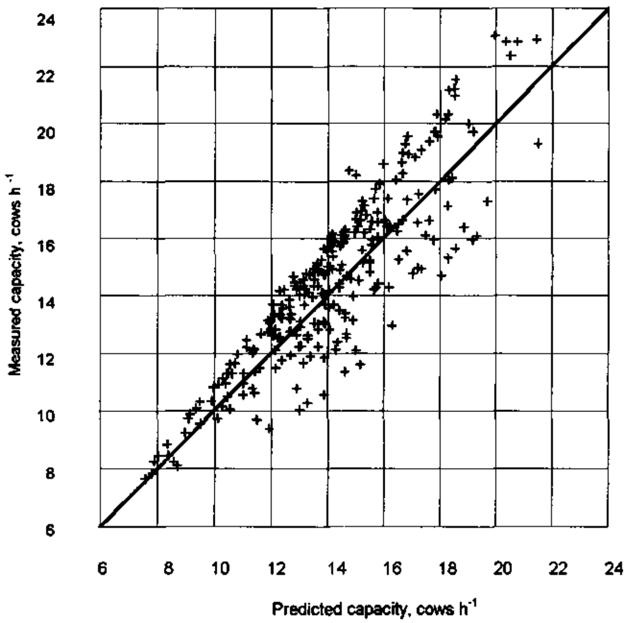


Fig. 3. Predicted capacities compared with measured capacities, calculated on the basis of one cycle. The full line indicates the ideal relation between the measured and predicted capacities

Table 4. Comparison between predicted and measured values of the milking capacity of a two-stall automatic milking system. Absolute and relative differences of the predicted and measured capacities

Milking no	Milking capacity: Predicted, cows/h	Milking capacity: Measured, cows/h	Difference: Absolute cows/h	Difference: Relative %
1	13.44	13.41	+0.03	+0.2
2	13.89	14.58	-0.69	-4.9
3	13.78	14.02	-0.24	-1.7
4	14.23	14.42	-0.19	-1.3
5	14.09	13.97	+0.12	+0.8
6	13.99	13.36	+0.63	+4.5

5. Application of the formula

5.1. Variation of robot wagon speed

Once a cow has entered a milking stall, it has to wait for the preliminary milking activities and these can be shortened only if the robot wagon moves at a higher speed. To examine this, Eqns (3), (5), (6) and the data of Table 2 are used to calculate the capacities for three speeds of the robot wagon, namely, 3, 6 and 9 m/min [Eqn. (7)].

Figs 4 and 5 respectively show the capacity (cows/h) and the percentage of idle time of the robot arm of an AMS arrangement with 1 to 10 stalls in-line and for three speeds of movement of the robot. Fig. 4 shows that when the speed increases from 3 to 9 m/min the maximum capacity changes from four to five stalls and amounts then to 23.6 cows/h. Now, the robot arm is continuously working and more than five milking stalls in-line does not improve the capacity for these robot-moving speeds.

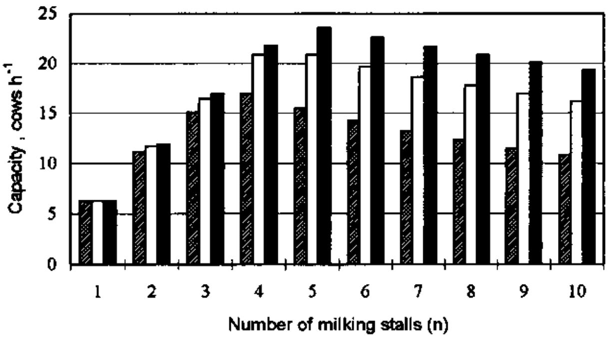


***Fig. 4.** The milking capacity (cows h^{-1}) for an automatic milking system with 1 to 10 stalls in-line and for three different speeds of the robot wagon. 3 m min^{-1} (shaded bar), 6 m min^{-1} (white bar), 9 m min^{-1} (black bar)*

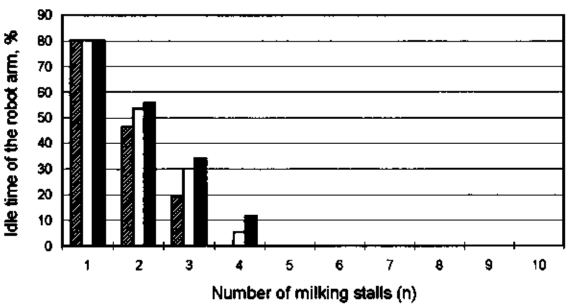


***Fig. 5.** The idle time of the robot arm (as percentage of the total process time) for an automatic milking system with 1 to 10 stalls in-line and for three different speeds of the robot wagon. 3 m min^{-1} (shaded bar), 6 m min^{-1} (white bar), 9 m min^{-1} (black bar)*

The maximum time interval between the entrance of the cow in the milking box and the attachment of the teatcups (INT) amounts for a two-stall AMS and with speeds of the robot movement of 3, 6 and 9 m/min respectively, to 2.58, 2.08 and 1.91 min. These intervals are acceptable.

5.2. Variation of average machine milking time and robot wagon speed

In all the model calculations an MMT_{av} of 6.5 min was used, milking twice a day. If the cows are milked more frequently the MMT_{av} changes. Ipema and Benders (1992) noted a daily MMT_{av} of 22.3 min (1 to 12 weeks in lactation) to 15.8 min (36 to 42 weeks in lactation) for milking three times a day and of 24.6 min (1 to 12 weeks in lactation) to 19.3 min (36 to 42 weeks in lactation) for milking four times a day.

To study the influence of the MMT_{av} in combination with the speed of the robot wagon, the capacity of the AMS is calculated with different MMT_{av} (4, 5, 6, 7 and 8 min). Figs 6, 7, and 8 show the curves for a milking robot provided with 2, 3 and 4 milking stalls. If the robot arm only serves two milking stalls the cycle duration of the robot arm is always shorter for all machine milking times than the cycle duration of the cow. The MMT_{av} directly affects the capacity and the relation can be deduced from Eqns (3) and (7) and written as :

$$Capacity = \frac{c_1}{MMT_{av} + c_2} \tag{8}$$

where c_1 = 60 n and c_2 is the cycle duration of the cow exclusive of the MMT_{av}. Capacity increases as the MMT_{av} decreases.

The effect of increased robot wagon speed on capacity is more pronounced in the 2 to 6 m/min interval than with higher speeds and with a lower MMT_{av} (e.g., 4 min; Fig. 6). We draw the same conclusions from Fig. 6 and Fig. 7. For a speed of 2 m/min for the robot wagon, the capacity with MMT_{av} of 4 min is equal to the capacity with MMT_{av} of 5 min (Fig. 7). In both cases the cycle duration of the robot arm is greater than that of the cow and determines the capacity.

Model calculations of a four-stall AMS show that the capacity is determined by the cycle duration of the robot arm with an MMT_{av} of 4 min (CDR > CDC). The equation of this curve (shown in Fig. 8) can be derived from Eqns (5) and (7) and written as :

$$Capacity = \frac{c_3 V_r}{c_4 + c_5 V_r} \tag{9}$$

where

$$c_3 = 60 \tag{10}$$

$$c_4 = (n+1)d/3 \tag{11}$$

$$c_5 = (MRD + RMR + RST + RAT + RET) \tag{12}$$

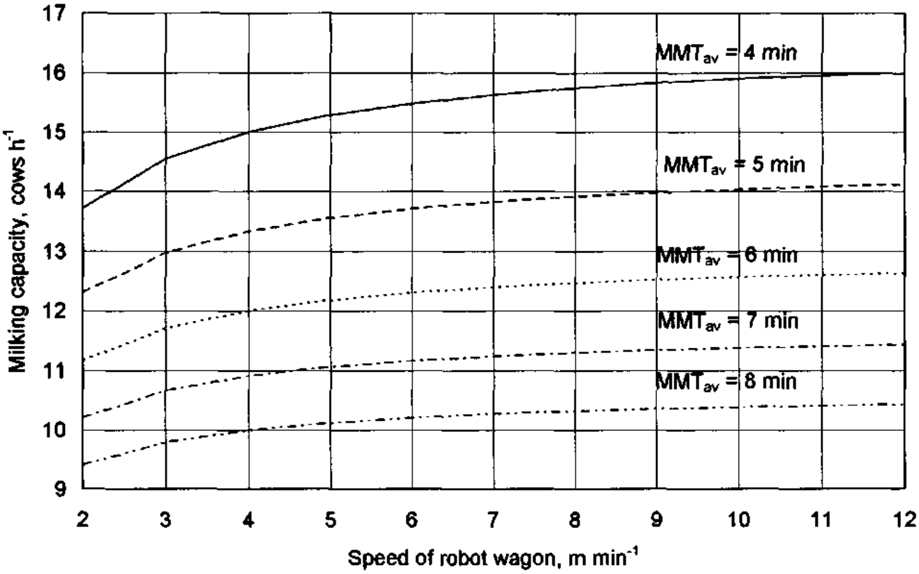


Fig. 6. *The milking capacity (cows h^{-1}) as a function of the speed of the robot wagon with different average machine milking times (MMT_{av}) and for a two-stall automatic milking system*

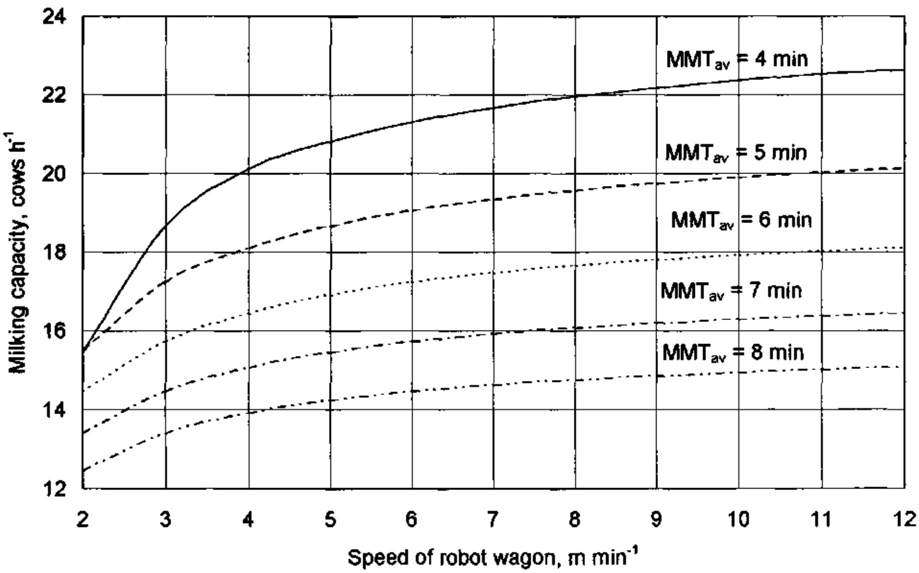


Fig. 7. *The milking capacity (cows h^{-1}) as a function of the speed of the robot wagon with different average machine milking times (MMT_{av}) and for a three-stall automatic milking system*

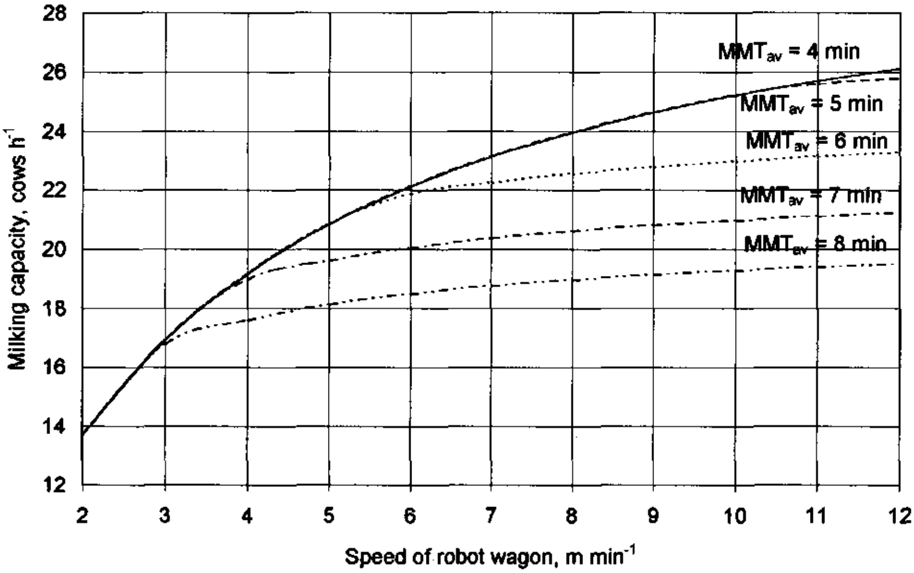


Fig. 8. *The milking capacity (cows h^{-1}) as a function of the speed of the robot wagon with different average machine milking times (MMT$_{av}$) and for a four-stall automatic milking system*

With an MMT$_{av}$ of 6 min the capacity of an AMS arrangement with four stalls in-line can be markedly improved by increasing the speed of the robot wagon. The capacity rises strongly in the interval of 2 to 6 m/min, but only slightly for a robot wagon speed greater than 6 m/min. In the latter, the capacity is determined by the cycle duration of the cow. The greater the MMT$_{av}$, the smaller the interval in which an increase in the speed of the robot wagon has a marked effect on the capacity.

According to the principle of time windows (Bottema, 1992), the robot is available three times a day for 3 h for half the herd, which needs to be milked three times a day, and two times a day for 3 h for the other half of the herd, which needs to be milked only twice a day. The AMS is available 15 hours a day. Increasing the robot wagon speed from 6 to 8 m/min results in an increase of the capacity of 1.84 cows/h (curve MMT$_{av}$ = 5 min; Fig. 8). Applying the principle of time windows and with respect to the above increase in capacity, the AMS can do 27.6 individual milkings per day more. Considering that half of the herd is milked three times a day and the other half is milked two times a day, the AMS can serve 11 cows more. The total milkable number of cows with the four-stall AMS would then be 144 cows. The same calculations for a two-stall AMS (robot moving speed of 8 m/min and MMT$_{av}$ of 5 min) result in a milkable number of 83 cows.

5.3. Means of increasing AMS capacity

The considerable capital investment involved in the establishment of an AMS merits a detailed forecast of the capacity and the possibilities to improve it. Improvements can be introduced on three levels : the cow, the system, or both.

(a) The travel distance of the cow should be as short as possible to decrease the time for entering the milking stall. The machine milking time of the cow can be influenced only by the frequency of milking.

(b) *Acceleration of certain processes of the system can lower the process times and shorten the cycle* duration of the milking process. The speed of the robot wagon can be increased (e.g., 12 instead of 6 m/min). When the robot wagon moves from one stall to the next, it does not have to stop at a rest point (as was assumed in the model). The movements of the robot arm can be accelerated without problems, e.g. the robot arm moving downwards to collect the milk rack (assume RMR = 0.15 instead of 0.20 min); and the robot arm returning to its initial position after the attachment of the teatcups (assume RET = 0.20 instead of 0.30 min). The removal of the milk rack (REM) and lowering it into its initial position (MRD) can be executed faster (REM = 0.15 instead of 0.20 min and MRD = 0.10 instead of 0.13 min). Process times such as opening and closing of doors (e.g., EBO, EPO, EBC), the cleaning and stimulation of the teats before milking (CST) can hardly be changed. Here, we retain the process times of Table 2.

(c) The performance of the milking robot can be improved by executing certain jobs simultaneously and by changing the sequence of certain processes (i.e., interventions on both levels, the cow and the system). The distance that the robot arm makes before starting its search for the teats of the cow can be shortened. Together with an improvement in the ultrasonic sensors, the average time for teatcup attachment can be reduced from 1.25 to 1.00 min. The opening of the entrance door of the milking stall and the milking parlour can be executed at the same time. This accelerates the starting activities of the cow.

The robot arm can move to a milking stall only if the milk rack with the teatcups is in its initial position. This occurs after the cow has been positioned in the box. If the milk rack is lowered immediately after removal of the teatcups at the end of milking, the robot arm can be moved as soon as the milking stall is free, so that robot arm movement takes place simultaneously with other stages in the process. Once the cow has entered the box it does not have to wait for the movement and the lowering of the robot arm or for the collection of the milk rack by the robot arm. This adjustment shortens the interval INT which comprises only scanning of the teats and attaching the teatcups. RMS_{max} and MRD can be omitted in Eqn. (3), which shortens the cycle duration of the cow.

The introduction of the above-mentioned improvements in the model for a two-stall AMS results in a total cycle duration of 9.27 min and a capacity of 13.0 cows/h (MMT_{av} = 6.5 min) and 15.4 cows/h (MMT_{av} = 5 min), instead of, respectively, 11.7 and 13.7 cows/h according to the current arrangement (Table 3). Applying the principle of time windows (see section 5.2.), these improvements increase the AMS performance with 19.5 and 25.5 individual milkings per day respectively and the milkable number of cows with 7.8 and 10.2 cows respectively.

5.4. Alternative AMS arrangements

Artmann and Schillingmann (1990) mentioned three types of milking stalls : a blind box (a box in which the cow enters forward and leaves backward), a walk-through box, and a tandem box (a box which has an entry and exit opening onto an access passage on the side away from the robot). Change-over of cows proceeds more smoothly in a tandem and walk-through box than in a blind box. In addition, with the tandem stall, the entrance and exit are free even when more stalls are installed in-line and individual care of cows is possible. The tandem box is therefore used in most developments.

At present only milking robots with one or two stalls are in use. If the robot arm could rotate around a vertical axis and serve stalls on its right and left side, it would be possible to develop a double tandem arrangement (Fig. 1B). This would shorten the distance travelled by the cows and by the robot wagon. As a result the parameters WAS in Eqn. (1), RMS_{max} in Eqn. (2) and RMS_{av} in Eqn. (4) change.

If the rotation time of the robot arm is equal to the time for moving the robot wagon from one stall to another, it can be shown that the operational time for the average movement of the robot for each milking stall can be written as :

$$RMS_{av} = \frac{(n+4)d}{6v_r} \tag{13}$$

The average distance ($d_{max,\,n}$) of the largest robot movements in all possible sequences of serving the milking stalls is 1.667 d for a 2 x 2 tandem arrangement. The travel distance of the cows in a double tandem (2 x 2 stalls) is half of that in a single tandem (1 x 4 stalls). In a 2 x 2 tandem arrangement the capacity (cows/h) would be 8.5% higher than in a one-row arrangement. Eleven cows more per day could be milked applying the time window principle as a milking frequency scheme.

Using the same approach of cycle analysis, the performance of a rotary tandem milking parlour combined with a milking robot can be estimated. In this milking parlour the cows stand on a moving platform and the robot is installed at a fixed place. The robot has only to scan the teats and attach the teatcups. Between the entry of the cows into the stall and the activities of the robot (scanning and attachment) the platform remains stationary. After the attachment, the platform rotates over a distance of one milking box. Cycle analysis shows that with a rotary tandem comprising five milking stalls a capacity of 29 cows/h can be reached. Installing more milking boxes on the platform is not advisable, because cycle duration is determined by the speed of robot activities. If these activities could be carried out faster (e.g., RST + RAT = 1.00 instead of 1.25 min), six milking stalls could be used and a capacity of nearly 39 cows/h could be reached. These figures must be considered to be maximum capacities. This type of milking parlour offers the possibility of milking a large number of cows within a short time during the summer grazing period with a minimum labour requirement and the possibility of milking the cows during the winter period based on voluntary visits of the cows to a selection unit and to the milking parlour. During the summer period, the herdsperson only has to collect the cows in a collecting area. An automatically controlled mobile fence could help to drive the cows into the milking parlour where milking is done automatically. The robot-rotary tandem combination will be expensive and could be recommended only for large herds.

6. Conclusions

In this paper we have devised a formula to calculate the capacity of a milking robot. The formula and the modelling approach can serve as a tool for an easy and quick determination of the capacity of different arrangements of an automatic milking system or milking robot.

A comparison with measurements in practice showed that the average difference between measured and predicted capacities of total milkings amounted to 2.2%. The model showed that the practical AMS arrangement with two milking stalls reaches a capacity of 11.7 to 13.7 cows/h, depending on the chosen MMT_{av}. By changing the sequence of certain activities and by programming to execute some activities simultaneously, idle times for cow and robot as well as the total cycle duration can be shortened which leads to an increase in the capacity. According to the model study the maximum capacity that can be reached with a two-stall AMS is 15.4 cows/h. The model showed that the robot wagon speed has a pronounced effect on the capacity for arrangements with a large number of milking stalls (> 2) and for herds with a short average machine milking time.

With the same modelling approach, formulae were developed to assess and evaluate fictitious AMS arrangements and to estimate capacities. A double or rotary tandem AMS arrangement can be a good alternative for an AMS with four or five milking stalls in-line. Arrangements with more than five milking stalls do not improve capacity, if the speed of the robot processes cannot be increased.

Although accurate functioning of the AMS is more important than the number of cows milked per hour, a higher capacity makes the robot economically more attractive (especially to large-scale farms) and more flexible to work with.

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Appendix A

The average robot movement is

$$\frac{\sum_{i=1}^{n} \sum_{j=1}^{n} d|i-j|}{n(n-1)}$$

Since

$$\sum_{i=1}^{n} \sum_{j=1}^{n} |i-j| = 2\sum_{i=1}^{n} \sum_{j=1}^{n} (i-j) = \sum_{i=1}^{n} i(i-1) =$$

$$\frac{n}{6}(n+1)(2n+1) - \frac{n}{2}(n+1) = \frac{n}{3}(n+1)(n-1)$$

The average robot can be written as :

$$\frac{(n+1)d}{3}$$

Appendix B

Table 5 shows the cow entrance times, derived from a simulation of milking in an AMS with 4 stalls in-line and 20 cows. The same activity times have been used as for the calculations in Table 3.

The duration of the first cycle in each milking stall differs from the durations of the subsequent cycles which all have the same duration. The average distance ($d_{max,\,n}$) of the largest robot movements with this sequence of serving the milking stalls is (n - 1) d or 3 d. The duration of one cycle is 11.65 min : e.g. the time interval between entrance of cow 5 and cow 9, i.e. 21.80 min - 10.15 min = 11.65 min.

The last cycles cannot be considered as complete cycles, e.g. cow 17 enters at 45.10 min and leaves at 55.55 min.

The last cow left the milking stall at 62.69 min (end of the milking session). Therefore, the milking time throughput is as follows.

$$\text{Milking time throughput} = \frac{20\ cows}{62 \cdot 69\ \text{min}} 60\ \text{min}\ h^{-1} = 19 \cdot 14\ cows\ h^{-1}$$

The milking capacity calculated with the formula is :

$$Capacity = \frac{n}{CDC} 60 = \frac{4}{11 \cdot 65\ \text{min}/\ cow} 60\ \text{min}\ h^{-1} = 20 \cdot 60\ cows\ h^{-1}$$

The proportion between milking time throughput and capacity calculated with the formula is in this case 92.9%, which can also be derived from Fig. 2.

Table 5. *Cow entrance times in the milking stalls derived from a simulation of milking in an automatic milking system with 4 milking stalls in-line and 20 cows*

Cow number	*Cow entrance time in milking stall No, min*			
	1	*2*	*3*	*4*
1	0.00			
2		0.72		
3			1.64	
4				2.76
5	10.15			
6		12.33		
7			14.51	
8				16.69
9	21.80			
10		23.98		
11			26.16	
12				28.34
13	33.45			
14		35.63		
15			37.81	
16				39.99
17	45.10			
18		47.28		
19			49.46	
20				51.64
Exit of last cow	55.55	57.93	60.31	62.69

Chapter 4

Labour research on automatic milking with a human-controlled cow traffic

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Abstract

The physical labour still required for automatic milking is studied in this paper. A calculation model for a task time program has been designed for the determination of the labour requirement for milking cows with a milking robot and using different working methods. Task times were derived from observations on commercial farms where automatic milking was combined with a human-controlled cow traffic and on an experimental farm where automatic milking was combined with computer-controlled cow traffic. Based on these work studies, activities are derived for automatic milking methods combined with five grassland systems. Seventeen variants are quantified by means of a case-study.

Calculations with the task time program show that the automatic milking method with human-controlled cow traffic applied during the whole year and with a milking frequency of three times a day results in physical labour savings for milking (37.9%). However, automatic milking with computer-controlled cow traffic results in a larger labour reduction (66.1%). The consequences of pasturing combined with automatic milking, on the labour requirement for milking are discussed.

Key words : automatic milking, model, task time program, labour requirement

1. Introduction

The integration of an automatic milking system (AMS) into a dairy farm requires a new approach of management and labour organisation. Ipema et al. (1992) showed that a lot of knowledge of the techniques of the milking process, the milk quality, the milking frequency, cow behaviour and herd management with automatic milking is already available. Information about labour demand and organisation related to automatic milking is still poor. In economic studies estimated labour data have been applied (Parsons, 1988; Harsh et al., 1992; Armstrong et al., 1992; Sangiorgi and Provolo, 1992; Esslemont, 1993). To base economic studies on more farm specific labour data, the changes in labour requirement on AMS farms have to be registered. To judge the impact of automatic milking on labour requirement, labour conditions and ergonomic demands, labour data are needed. Labour data form the basis for labour budgeting and offer tools to discover bottlenecks in (operational and tactical) labour planning on AMS farms.

Of all the jobs that have to be executed on a dairy farm, it is obvious that milking is affected most by the introduction of an AMS. Automatic milking factorizes the cow-machine-man relation which can be found in traditional milking parlours (Sonck et al., 1991) into a cow-machine system controlled by a computer and the herdsman as supervisor. The final goal is that the continuous presence of the herdsman in the milking parlour will no longer be needed. Milking, which demands intensive physical and mental efforts from the milker in conventional milking parlours (Belt and Zegers, 1984; Belt, 1984; Stål and Pinzke, 1991) becomes then merely a task of supervision.

The human role in automatic milking needs a better description. His function and labour content will change with the way in which the AMS is integrated into the total farm (labour) management concept. Related to this integration, some options are open to the farmer viz. the milking frequency, cow traffic to and fro the AMS and applied grazing system :

(1) All cows can be milked with the same frequency (2, 3 or 4 times a day) or cows can be milked with a frequency based on individual cow's criteria (Devir et al., 1993).

(2) In relation with cow traffic, three working methods can be distinguished.

* *Automatic milking with computer-controlled cow traffic (AM-CCT).* The cow traffic stream in the dairy is controlled by using one-way gates (Ketelaar-de Lauwere, 1992a) and selection unit(s) in front of the milking unit (AMS) (Swierstra and Smits, 1989). One-way gates force the cows to go from the lying area to the feeding area of a cubicle house via the AMS. A selection unit recognizes and selects the cows which need to be milked. An on-line dairy control and management system controls the traffic and the automatic milking and feeding routine (Devir, 1992). The entire system works fully autonomously.
* *Automatic milking with uncontrolled cow traffic (AM-UCT).* This option can be found during the introductory phase of an AMS on a commercial farm. The AMS is installed without changing the layout in the cowshed and without provisions to control cow traffic. However, Ketelaar-de Lauwere (1992b) observed that fewer cows visited the selection system with a passive routine than with a forced routine. A free cow traffic may require more labour from the herdsman to fetch the cows and bring them to the AMS in order to maintain the milking frequency. From an

organisational point of view, irregular interruptions of farm operations other-than-milking have to be avoided as much as possible. Therefore, this option is rejected in this study.

* *Automatic milking with human-controlled cow traffic (AM-HCT).* The herdsman can collect the cows at fixed time intervals and hold them in a waiting area in front of the AMS. This procedure prevents the fetching of individual cows at inopportune moments of the day. Here, the AMS replaces only the milker to attach the teatcups. The cows with which the automatic teatcup attachment fails after some attempts, can be separated. At the end of a milking, the separated cows can be milked under supervision of the herdsman. As the milker is released from the milking activities during milking proper, a substantial labour reduction might be achieved.

(3) During the summer period different grazing systems can be applied :

* unrestricted grazing : cows remain in the pasture 24 h a day;
* restricted grazing : cows are during one long period of the day in the pasture (8 to 12 h);
* restricted grazing : cows are during one short period of the day in the pasture (4 h);
* restricted grazing : cows are during two short periods of the day in the pasture (2 x 4 h);
* zerograzing : cows remain in the cowshed during the summer period and receive fresh cut grass or silage.

The automatic milking system can milk cows completely automatically. However, the system is very flexible in use. Human intervention and manual operation of the AMS are possible (e.g., manual attachment of the teatcups). This option (manual operation) is only chosen in special cases (e.g., milking separated cows) and is not considered as a working method.

The combination of the above-mentioned options results in various working methods with the AMS which may fit each into different management styles and farming plans. To derive the role of the milker and to determine the labour requirement for milking for each of these methods, the work elements which need to be performed by the milker, have to be appointed. Therefore, a research was conducted on commercial farms with a 'Prolion' automatic milking system (Bottema, 1992). The main goal of this research was the development of a calculation model for the determination of the labour requirement for milking with different AMS working methods. Results of work studies with automatic milking and a human-controlled cow traffic (AM-HCT) are used as a basis for the model.

The following questions are relevant to this research :

- To what extent is the automatic milking system independent of human intervention ?
- Which work elements does the milker have to perform and what are the basic times ?
- Can the results of the work studies be applied on other farms ?
- Which work elements do return or expire in the other working methods and what is the labour requirement for milking with these methods ?

This labour research describes the effects of various working methods with the AMS on milking and is limited to the physical labour still required for automatic milking. The effects on the other-than-milking jobs and in general on labour organisation are the subject of further research.

2. Materials and methods

2.1. Layout

Work studies were performed on a commercial farm to collect basic times of work elements related to automatic milking with a human-controlled cow traffic (AM-HCT). On this farm, 52 cows were housed in a loose house with 49 cubicles in two rows and a feed area with a feed fence (45 feeding places) (Fig. 1). Roughage (maize- and grass-silage) was supplied ad libitum at the feed fence. Two concentrates dispensers were provided, one accessible from the lying area, the other from the feeding-exercise area. The milking area and the feeding-exercise area were only separated by gates. Very remarkable in the layout was the presence of a crossing at the entrance of the AMS-area (see movement of cows). An AMS of the type Prolion Development was installed in the former herringbone milking parlour. The AMS comprised two milking stalls installed in tandem (Bottema, 1992). A robot wagon equipped with a robot arm moves along rails from one milking stall to another to attach the teatcups. The attachment system is described in Hogewerf et al. (1992). Automatic feeders for concentrates are installed in each milking stall. Cow are rewarded with 1 kg of concentrates per visit. The exit of the milking area debouches in the feeding section of the loose house. A diversion gate at the exit of the milking area offers the possibility to isolate particular cows in a holding area. The holding area comprises five feeding places and a slatted surface of 9 m^2. The aim of a holding area is to isolate cows which either have not been attached to the robot and remain therefore unmilked during the fully automatic operation of the AMS or which require special care. An isolated animal can easily be brought back in the AMS-area when it is in the neighbourhood of the AMS (usually at the exit). As the milker was continuously present during the observed milkings, he could immediately intervene when it was necessary. Therefore, the holding area was not used for the mentioned purpose. The working place of the milker was about 90 cm below the milking stalls of the AMS, which contributed to a good view on the attachment of the teatcups. The terminal stood in the corner of the milking pit (Fig. 1). From this point the milker supervised the milking process.

2.2. Movement of cows

Just before milking, the cows were collected from the pasture (in the evening) or from the loose house (in the morning) and assembled for milking in a waiting area, i.e. the lying area bounded by the cubicles, and gates 2 and 5 (Fig. 1). Towards the end of milking the cows were driven into a smaller waiting area bounded by the cubicles of the lying area and gates 2 and 4. The cows entering the AMS-area, were crossing the milked cows which left the house and were proceeding to the pasture. As soon as a milking stall became free, the entrance door (texas-door) of the milking area opened. The two one-way gates, situated on the crossing and in the passage leading to the pasture, were blocked by the open texas-door. The cows which were to be milked and entered the AMS-area had priority over the milked cows. The animals entered the milking stall through a side-passage (slatted floors). As soon as the cows were milked they left the milking stalls via the side-passage and through a one-way gate. Immediately after the morning milking the cows had the choice to go to the pasture or to the feeding-exercise area. During the evening milking, the exit to the pasture was blocked (with a rope = gate 3). A one-way gate (gate 1) installed during the evening milking, prevented the cows of returning to the exit of the AMS-area.

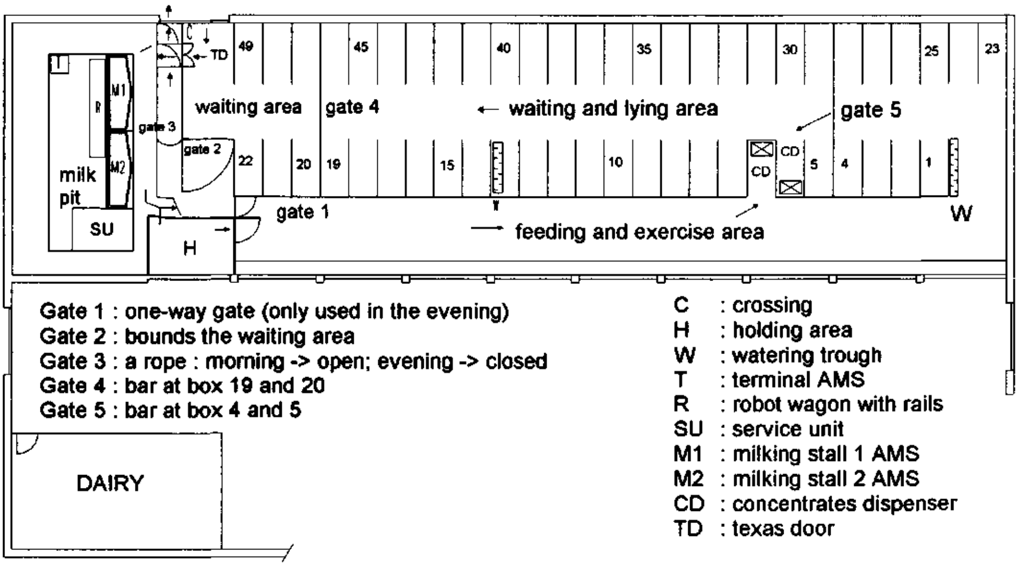

Fig. 1. *Layout of the cubicle loose house with automatic milking system*

2.3. Method of time study

Prior to the detailed observations, the work of the milker was followed during a test milking. The entire milking job was split into different work elements. A summary of work elements and their corresponding codes was made. As the working method was different for morning and evening milkings, we had to observe both. Work studies of three morning (M1, M2, M3) and three evening milkings (E1, E2, E3) were carried out in June 1993. To compare the milkings, the observations were performed in a short period. The difference between first and last milking was only 8 days. To register the start and end of the work elements at the right moments, the basic times were recorded by one and the same person. This information was collected by means of a hand-held microcomputer (type HUSKY HUNTER 16), with a time study software program (Sonck and van der Schilden, 1994). A code, a description, the clock time, the number of features, the values of the features and the basic time of each work element were saved in a data file. The files of the hand-held computer were subsequently transferred and imported on the hard disk of a PC. The data were processed partly by a calculation program (QuickBasic) and partly by a spreadsheet program. We extracted the following data from the AMS terminal : date, cow number, number of the milking stall (1 or 2), actual time of cow identification at the moment the cow enters the milking stall, actual time that the robot arm picks up the milk rack and the reference sensor starts searching for the reference teat, actual time when the exit gate of the milking stall opens (at the end of milking a cow), the number of attempts of teatcup attachment and the milk yield.

Additional observations were made on a second commercial farm using the AM-HCT method (Swartjes, 1993) and on a research farm where an AM-CCT method as described in Devir et al. (1993) was tested. It enables us to check whether the same work elements as in the described farm return.

3. Results

3.1. General results of the work study on the farm

To evaluate to what extent the automatic milking is independent of the milker, all work elements of the job milking are divided in three categories :

(1) *OBSERVATION.* This means that the milker does not have to intervene in the AMS or in cow traffic. The milking process proceeds flawlessly and the milker merely observes.

(2) *SERVICE AMS/ CONTROL WORKING AMS (S/C AMS).* These contain all the work elements in the course of which the milker operates the user interfaces of the AMS and controls the milking process. Examples : searching in the menu of the AMS-program, changing co-ordinates of the reference teat in the data files, initializing the robot (on terminal), changing the length of the milking stall by pressing a button on a board (box management unit board = BMU board).

(3) *PHYSICAL WORK (PW).* This contains all the work elements in the course of which the milker does not or not only press buttons or keys on the terminal. Examples : manual teatcup attachment, driving the cows in the house, intervention in the cow traffic, repairing parts of the AMS.

The physical labour requirement of the milker per cow, defined as the time required for all non observation work elements executed by the milker during the operation milking and calculated per cow, or (S/C AMS + PW)/(number of cows), can serve as a measure of (in)dependence of the AMS from the milker. Based on Table 1, a milking lasted about 5 to 5.63 h. The milking time expressed per cow was 5.75 to 6.50 min. The physical work and the service/control of the AMS in the milking time per cow (= the physical labour requirement of the milker per cow) was 1.05 and 1.16 min/cow for resp. morning and evening milkings. The difference was caused by the work elements 'displacement to the cows in the pasture' and 'driving the cows in the pasture and collecting them in the waiting area of the house'. These work elements were only performed in the evening, as the cows remained in the shed during the night. In the morning the milker only had to drive the cows in the waiting area. Remarkable was the fact that the milker spent 4 to 9 times as much time on the physical work than on the service/control of the AMS. Especially the physical work at the start and end of a milking were responsible for this difference.

***Table 1**. General results of the milkings on the farm*

Milking	Milking time	S/C AMS		PW		OBSERVATION		Number of cows	Milking time/cow	Phys.labour requirement
	(h)	(min)	(%)	(min)	(%)	(min)	(%)		(min)	(min)
M1	5.17	8.22	3	36.65	12	264.96	85	52	5.96	0.86
M2	5.52	9.91	3	48.04	15	273.11	82	52	6.37	1.11
M3	5.08	4.13	1	54.16	18	246.63	81	49	6.22	1.19
E1	5.63	8.41	2	51.08	15	278.36	82	52	6.50	1.14
E2	4.98	5.68	2	60.51	20	232.89	78	52	5.75	1.27
E3	5.02	5.95	2	46.40	15	248.64	83	49	6.14	1.07
Morning [1]	5.34	9.07	3	42.35	13	269.03	84	52	6.16	0.99
Evening [1]	5.30	7.05	2	55.80	18	255.62	80	52	6.12	1.21
Morning									6.18	1.05
Evening									6.13	1.16

M = morning milking; E = evening milking.
S/C AMS = Service and Control of AMS ; PW = Physical Work.
[1] Excluding M3 and E3 because only 49 cows instead of 52 were milked during these milkings.

To highlight the spread of work elements over an entire milking, the actual milking time within the milking process was divided into periods of 15 min. The proportion of the three categories of work elements was calculated for each period. Fig. 2 gives the proportional distribution of the work elements for each of the six milkings and shows that the contribution of physical work was relatively high at the start and end of a milking. The milker had to perform some specific work elements. Between those initial and final activities, the AMS worked for 90% of the time independent from the milker. Observation by the milker was mainly influenced by the good or less good working of the robot and by the cow traffic around and to the AMS. In comparison to milking in conventional milking parlours (Ordolff, 1972; Sonck et al., 1991), the milking operation according to the automatic milking method with a human-controlled cow traffic can be divided into three main groups of activities : the make ready activities of a milking (start), the milking proper (milking) and the put away activities of a milking (end). The following paragraph describes these activities in more detail.

3.2. The make ready, milking and put away activities

Make ready and put away activities

These activities were overlapping the milking proper in time. Before collecting the cows in the waiting area, the milker started the AMS and admitted the first two cows into the milking stalls. Sometimes, unexpected events during the milking of the first two cows interrupted the make ready activities. The same remark can be made for the put away activities when these were partly overlapping with the milking. In our evaluation, we eliminate these overlaps and use a chronological sequence of make ready, milking and put away activities. A working method using the shortest travelling distances for the milker to accomplish the make ready and put away activities of

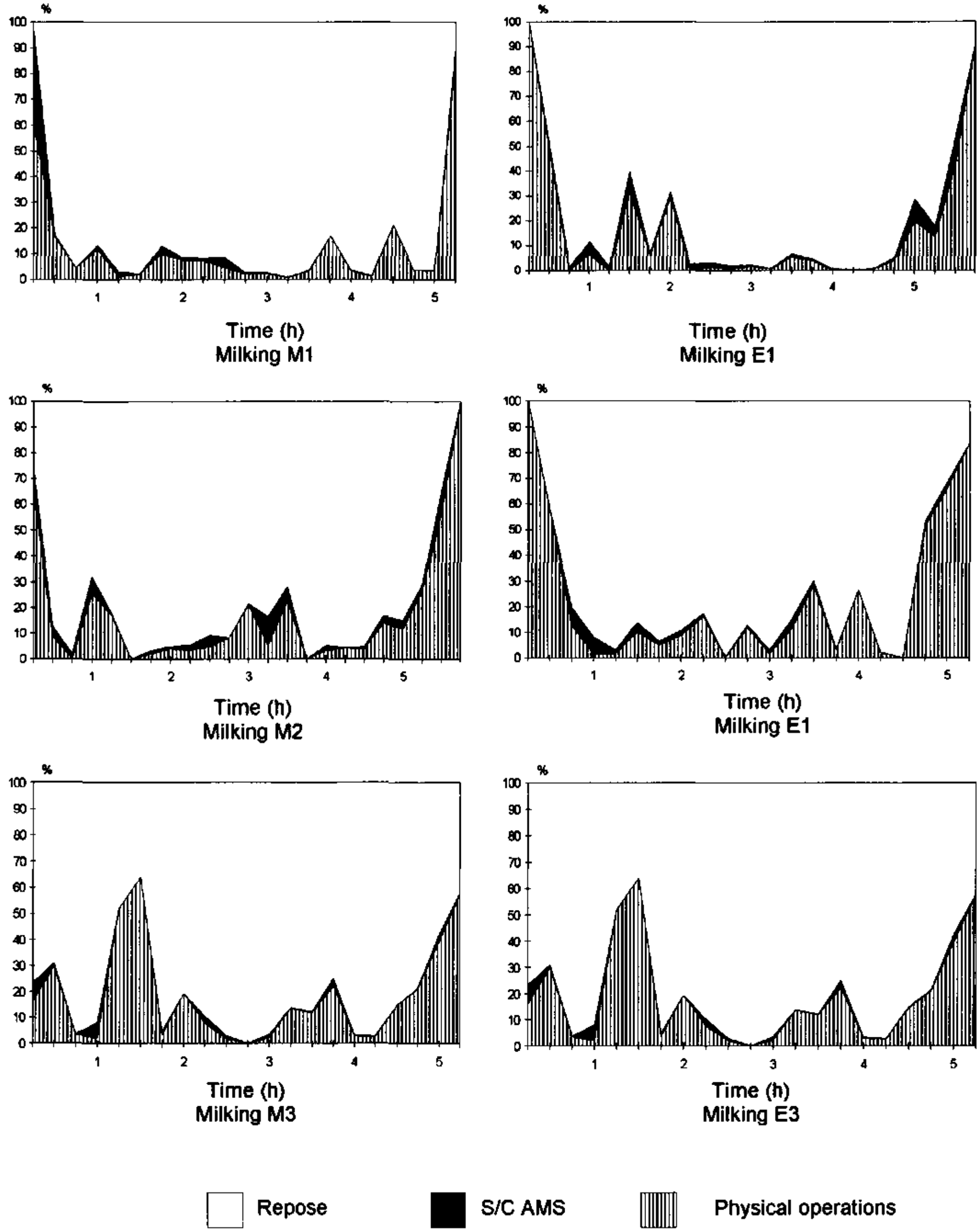

Fig. 2. Proportional distribution of the operations (repose, service/control AMS and physical operations), during morning (at left) and evening (at right) milkings

the operation milking is presented. The element times for the various work elements during the start and end of a milking were registered on the farm. The basic times as mean of the element times were rounded off to a multiple of 0.05 min. Travelling times of the milker were calculated on the basis of travelling distance and a speed of movement of 1 m/s. As the cows were coming from the pasture in the evening and from the cubicle house in the morning, the make ready work elements of the evening differ from those of the morning. Table 2 lists the make ready work elements (with basic times) of the AM-HCT method for a morning and evening milking sequence. As this work is comparable with that in conventional milking parlours, we assumed a rest and disturbance allowance as mentioned in the 'Task Time Books of IMAG-DLO' (Anonymous, 1973). Therefore, a rest allowance of 10% and a disturbance allowance of 3% are included in the total labour requirement. The rest allowance is for rest and personal care and is determined by the work load. Disturbance allowance is intended for the correction of little disturbances appearing during the farmer's work.

Table 2. *The sequence and basic times of the make ready work elements during morning and evening milking with automatic milking and human-controlled cow traffic*

Work element	*Time (min)*	*S.D.* * *(min)*	*Sequence number* *Morning*	*Evening*
Entering the dairy	-	-	1	1
Putting the delivery pipeline in the milk tank	0.35	-	2	2
Displacement milker : dairy to milking area	0.15	-	3	3
Placing the milk filter in the pipeline	0.85	0.07	4	4
Starting the system and the computer + control of start	0.50	0.06	5	5
Initializing the robot	0.25	0.15	6	6
Cleaning with water : millking stalls	0.55	0.22	7	19
floor milk pit	0.45	0.10	8	20
slatted floors around AMS	1.00	0.11	9	21
Displacement milker : milk pit to slatted floors behind milking stall 2	0.20	-	10	7
Closing gate 2 that bounds the waiting area	0.15	0.08	11	10
Removing the rope (gate 3)	0.15	0.07	12	
Walking in the feeding-exercise area on the slatted floors and driving the cows which were standing or lying there, in the large waiting area (behind gate 5)	2.00	0.40	13	
Placing a bar (gate 5)	0.10	0.04	14	12
Walking to the milk pit via the feeding-exercise area	1.00	-	15	
Installing one-way gate : gate 1	0.15	0.08		8
Hanging a rope (gate 3) in the exit passage before the crossing	0.15	0.07		9
Displacement milker to gate 5	0.40	-		11
Displacement milker to cow-entrance of the cowshed	0.45	-		13
Opening the gate of the cow-entrance	0.10	-		14
Displacement to the cows in the pasture	3.50	-		15
Driving cows to the waiting area of the cubicle house	15.00	-		16
Closing gate of cow-entrance	0.10	-		17
Displacement milker : cow-entrance to milk pit	0.20	-		18
TOTAL LABOUR REQUIREMENT (min)			7.70	24.60
TOTAL LABOUR REQUIREMENT (min)(incl. 10% rest allowance + 3% disturbance allowance)			8.72	27.87

* S.D. = Standard Deviation. There are no standard deviations for basic times of work elements which are calculated (e.g. displacements).

The make ready time was 8.72 and 27.87 min for respectively the morning and the evening milking. The difference was mainly due to the fact that the cows had to be collected in the pasture and driven into the waiting area. This represented the major part of the make ready work of an evening milking. In the morning, most of the labour went to the installation of the gates in the cubicle house and to the collection of the animals in the waiting area. The put away work elements of the morning and evening milking were identical. Based on Table 3, the total labour requirement of the put away work elements amounted to 16 min. This routine included the external cleaning of the AMS and the cleaning of the surrounding floors. Make ready and put away work amounted to about 25 min for a morning milking and 44 min for an evening milking.

Table 3. *The basic times the put away work elements of automatic milking with human-controlled cow traffic*

Work element	*Time (min)*	*S.D.* (min)*
Displacement milker : milk pit to slatted floors behind milking stall 2	0.20	-
Opening gate 2 of waiting area	0.15	0.08
Displacement milker : to gate 4	0.10	-
Removing bar (gate 4)	0.15	0.08
Displacement milker : from gate 4 to milk pit	0.30	-
Protecting the sensors	0.30	0.15
Emptying the milk buffer stock by pressing a button	1.00	0.16
Displacement milker : from milk pit to dairy	0.15	-
Pulling the milk pipeline out of the milk tank	0.35	-
Displacement milker : from dairy house to milk pit	0.15	-
Removing filter	0.70	0.13
Cleaning milk meter of milking stall 1	0.75	0.10
Cleaning milk meter of milking stall 2	0.75	0.10
Cleaning the holder of the filter and the rails of the robot	0.60	0.16
Starting the cleaning program on the terminal	0.30	0.17
Opening one door of each milking stall for cleaning	0.15	0.07
Cleaning milking stall 1	1.45	0.50
Cleaning milking stall 2	1.45	0.50
Cleaning the slatted floors at the entrance and exit of the AMS-area	3.00	0.50
Cleaning the floor of the milk pit	2.00	0.68
Displacement milker : from milking area to dairy	0.15	-
Leaving the dairy	-	
TOTAL LABOUR REQUIREMENT (min)	14.15	
TOTAL LABOUR REQUIREMENT (min)(incl. 10% rest allowance + 3% disturbance allowance)	16.03	

* S.D. = Standard Deviation. There are no standard deviations for the basic times of work elements which are calculated (e.g. displacements).

Operations during the milking proper

On this farm, milking (excluding make ready and put away work elements) required 4 to 5 hours per milking or 5.5 min/cow. Half a minute was required for physical work and service and control of the AMS. The milker had nothing to do in the remaining time. The percentage of observation activities during milking was circa 90%. The most repeating PW and S/C AMS work elements executed by the milker are shown in Table 4. Number of observations, basic times and their standard deviation are given for each work element.

* *Help with teatcup attachment.* To stop the automatic search for the teats by the AMS robot arm (usually after five attempts), the milker had to operate a switch on the MAM-board (Milk Apparatus Management). To attach the teatcups manually, the milker had to switch on teat detection, press a button to start the vacuum, move the milk rack under the udder and attach the teatcups. This

operation lasted 0.30 min. The basic time for switching the teat detection system on and off was only 0.03 min. Table 5 gives the number and percentage of animals for which the teatcups were

Table 4. *The most repeating work elements of the milker during milking*

Work element	*N*	X_m *(min)*	*S.D.(min)*
1) Help with the attachment of the teatcups			
Operations switch manual/automatic attachment	56	0.034	0.016
Attachment without robot (manual)	81	0.30	0.10
2) Operations on terminal of the AMS			
Changing adjustments	44	0.19	0.13
Initializing the robot	12	0.23	0.17
3) Driving a cow from waiting area to entrance of AMS-area	15	0.69	0.20
4) Operation on/off switch of teat detection	65	0.031	0.015
5) Reducing the waiting area from gate 5 to gate 4 (including driving cows)	6*	2.80	0.92
6) Troubleshooting and repair			
Total time per milking for troubleshooting and repair	6*	9.07	2.91

N = number of observations of a work element during 6 milkings or (*) number of milkings.
X_m = mean of element times (min).
S.D. = Standard Deviation (min).

attached respectively automatically, with manual intervention and completely manually. When something tended to go wrong with the attachment process and the milker could correct it manually, it is called an 'attachment with manual intervention'. For example : the attachment of three teatcups was successful but manual correction was required to position the fourth teatcup. This minor intervention prevents an unnecessary repetition of the search process by the sensors of the robot arm. For this herd, the success rate (%) for automatic teatcup attachment varied between 61% - 73%. On an average, the milker had to attach the teatcups on the udder of 13 cows per milking. This number includes the animals that were not suitable for automatic attachment by the robot, because of a deviating udder form. On this farm we counted five animals with such an anomaly.

Table 5. *Teatcup attachment results for each milking*

Milking	*With robot*		*With manual intervention*		*Manual attachment*	
	(number)	*(%)*	*(number)*	*(%)*	*(number)*	*(%)*
M1	38	73	4	8	10	19
M2	32	61	2	4	18	35
M3	34	69	2	4	13	27
E1	36	69	4	8	12	23
E2	35	67	2	4	15	29
E3	32	65	7	14	10	21

M = morning milking; E = evening milking.

* *Work on the AMS-terminal*. The standard deviations of these work elements were high considering the mean values. Commands could be given to the system by means of a user-friendly menu-driven program. The time required to enter a command with the program depended on the displayed menu or submenu and on the menu or submenu that had to be selected. Moreover, the time needed to change the settings was determined by the number of settings the milker wanted to change. However, this went so fast that it was not possible to follow, moreover the hand-held computer was unsuitable for recording such times.

'Initializing the robot' is a work element that is normally performed at the start of a milking and that brings the robot (robot wagon with robot arm) in an initial position. If the robot lost its position during milking, it needed initializing again. This happened 12 times during six milkings or twice per milking whilst initialization was always performed at the start of a milking.

* *Driving a cow from the waiting area to the entrance of the AMS area.* The animals which were waiting in a collection yard visited the AMS voluntarily. Only 15 cows over six milkings (5%) had to be driven to the entrance of the milking stall. In addition, two animals were responsible for 9 of these misses. The basic time of this work element amounted to 0.69 min.
* *Operating the on/off switch for teat detection* (see higher).
* *Reducing the waiting area from gate 5 to gate 4 (including driving the cows).* The milker reduced the waiting area when only 15 cows were left awaiting to be milked. This work element lasted nearly 3 min.
* *Repair.* Table 6 shows that about 9 min per milking were spent on repair and that about 10 failures were observed per milking. For example : The high element time in M3 includes the replacement of the pneumatic cylinder that moves the teatcups during milking (9.75 min), repairing the long milking tubes (1.80 min) and tinkering with the robot arm (1.22 min).

Table 6. *Labour requirement per milking for solving failures*

Milking	*Labour requirement (min)*	*Number of failures*
M1	6.51	8.0
M2	7.67	14.0
M3	14.62	13.0
E1	8.14	11.0
E2	11.03	9.0
E3	6.46	9.0
Mean value	9.07	10.7

M = morning milking; E = evening milking.

3.3. Generalization of the results and development of a calculation model

Additional observations on a second commercial farm (see appendix A and B), learned that the same work elements as described in the previous paragraphs are found in the AM-HCT method. Only, the work routine and the basic times for the work elements related to cow traffic (e.g. placing gates, driving cows) were different and depended on the layout and type of the cubicle house, the number of cows, the distances of displacements and the number of gates. We also observed milkers on a research farm where automatic milking with computer-controlled cow traffic (AM-CCT) was tested (Devir et al., 1993). In comparison with the AM-HCT method, the milkers had only to perform activities related to external cleaning of the AMS and cleaning of the milking area, rinsing the milk installation and starting up the system after cleaning. With this method, the first six work elements of Table 2 and the work elements of Table 3, excluding the first five, return.

Generalization of the results is possible but with certain limitations. Type, layout and dimensions of the cowshed and location of the pastures in relation to the AMS-area and the cow house all affect the activities involving transport of cows and displacements of the milker. In general, three types of houses can be distinguished among dairy farms : the stanchion barn, the littered loose house and the cubicle loose house. As the application of the AMS so far has mainly been tested in cubicle loose houses, the calculation model is restricted to this type of house. Seven layouts of cubicle houses are considered in the model to define standard work routines.

As already mentioned in the introduction, the AM-CCT and AM-HCT methods can be combined with (five) different grassland management systems which affect the milking routine. In addition, different milking frequencies can be applied : twice a day, three times a day or a milking frequency relative to the individual cow's daily milk production. Combining these options results theoretically in 30 different methods. To evaluate the methods and to calculate the labour requirement for automatic milking, a task time program is written (in QuickBasic 4.5) based on the visual model shown in Fig. 3. This model simplifies the different ways of dairy cow traffic on a farm. The herdsman decides which way the cows are driven through the whole farm system and with which frequency. The selected cycle and its frequency, affect the labour requirement. The four lines GS1, GS2, GS3 and GS4 in the model represent the grazing patterns of the cows. The four grassland systems are : unrestricted grazing (1), restricted grazing during one long period (2), during one short period (3) and during two short periods per day (4). A fifth grassland system, also considered in the program, is zerograzing. With e.g. AM-HCT, zerograzing and a milking frequency of 3 times a day, the cows are moved from the 'lying area' to the 'waiting area' (WA), enter the automatic milking system (AMS), leave the AMS and enter the 'feeding area'. The cows finally return, via a one-way gate, to the lying area (see Fig. 3). According to the milking frequency, the herdsman repeats the cycle three times a day. Outside these milking times the cows have free access to the feeding area (dotted arrow from WA to feeding area). For the AM-CCT combinations, we assume that the cows are driven to the AMS by the milker and do not visit the AMS voluntarily during the grazing periods.

This visual model is translated into formulas for the calculation model, which can be condensed into two general formulas.

The first general formula calculates the labour requirement per 24 h for the AM-HCT method. We assumed that the milker can walk away for a longer period after the make ready activities and do other work like e.g. feeding. However, control visits have to be done during milking.

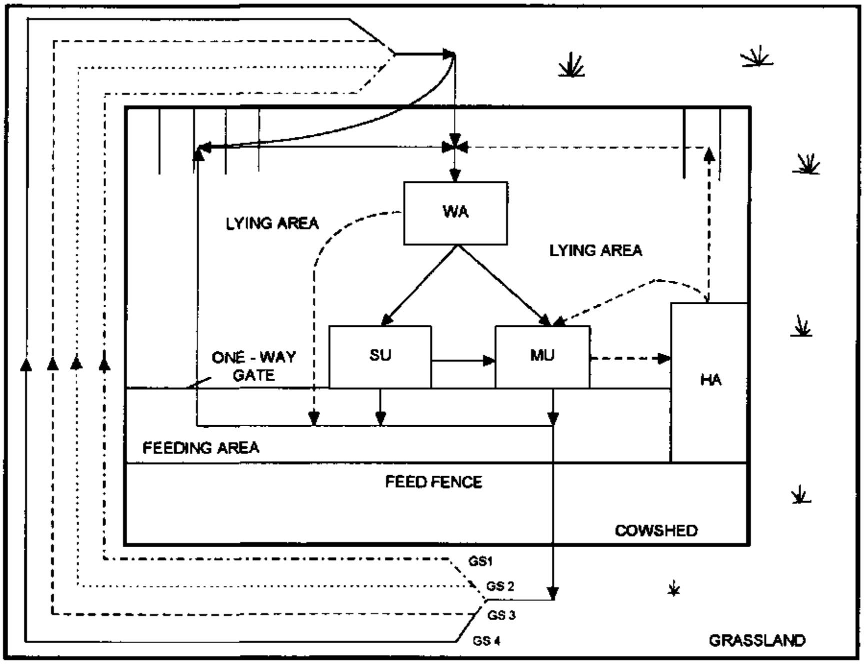

Fig. 3. *Visual model of cow traffic with automatic milking in a total farm system, used as basis for a task-time program for automatic milking; MU = milking unit; SU = cow selection unit; WA = waiting area; HA = holding area; GS1...2 = grazing systems; GS1 = unrestricted grazing; GS2 = restricted grazing during one long period; GS3 = restricted grazing during one short period; GS4 = restricted grazing during two short periods*

$$LR_{AM-HCT} = \left[\sum_i n_i \cdot MR_i + \sum_j n_j \cdot PA_j + \sum_k n_k \cdot HCTCont_k + \sum_l n_l \cdot Cowin_l + \sum_q n_q \cdot HCTU_q \right] \cdot \left(1 + \frac{DALL}{100}\right) \cdot \left(1 + \frac{RALL}{100}\right) \qquad (1)$$

where :

LR_{AM-HCT} = the labour requirement per 24 h for the AM-HCT method (min);

MR_i = the labour requirement for a group i of make ready work elements (min) (remark : the kind of work elements of a group is determined by the cow traffic before and after milking);

PA_j = the labour requirement for a group j of put away work elements (min) (same remark as for MR_i);

$HCTCont_k$ = the labour requirement for supervision and control during visit k of the milker to the AMS area (min). It includes displacements from the house to the dairy and vice versa, checking cow characteristics on the terminal, driving cows from the waiting area to the entrance of the AMS area and displacements of the milker in the cowshed. We assume X visits per milking (with X = [number of cows/15] - 1) and one PC control per milking of all the cows, done during the X visits;

$Cowin_l$ = the labour requirement to drive cows from the pasture (with symbol l) to the lying area of the cubicle house (min). This work is only required when short grazing periods are applied which are not followed by milking. Therefore, these activities are not considered as make ready activities of milking, but as additional activities resulting from the chosen grazing method. When these activities are followed by milking, they are considered as make ready activities of milking (part of MR_i). We assumed that 'driving the cows out the cowshed and back to the pasture' is immediately performed after milking. Therefore, these activities are always part of a group of put away work elements (part of PA_j);

$HCTU_q$ = the labour requirement for an unexpected work element q (e.g. repair, milking of cows separated in the holding area) (min);

n_i, n_j, n_k, n_l, n_q = the frequencies per day of the respective groups of work elements;

DALL = disturbance allowance (%);

RALL = rest allowance (%).

The second general formula calculates the labour requirement per 24 h for the AM-CCT method. It is a sum of different groups of work elements that have to be executed during the day. As milking is done during nearly 24 h a day, a division in make ready, put away and milking proper activities was not made. It is assumed that the AMS works independently and that cows with a deviating behaviour are not present. Only a few control visits are needed during the day.

$$LR_{AM-CCT} = \left[m \cdot (Cl + Start) + \sum_u n_u \cdot CCTCont_u + \sum_v n_v \cdot (Cowin_v + Cowout_v) + \sum_w n_w \cdot CCTU_w \right] \cdot \left(1 + \frac{DALL}{100}\right) \cdot \left(1 + \frac{RALL}{100}\right) \quad (2)$$

where :

LR_{AM-CCT} = the labour requirement per 24 h for the AM-CCT method (min);

Cl = the labour requirement for work elements related to rinsing of the milking installation and to cleaning of the milking area (min);

Start = the labour requirement for the starting-up procedure of the AMS after a cleaning period (min);

$CCTCont_u$ = the labour requirement for supervision and control by the milker during visit u of the milker to the AMS area (min). This includes displacements from the house to the dairy and vice versa, checking cow characteristics on the terminal, a supervisory walk through the cowshed and in the feed alley. We assume Y visits per day (Y = determined by the farmer) and a PC control of all the cows twice a day and done during the Y visits;

$Cowin_v + Cowout_v$ = the labour requirement for driving the cows from the pasture (with symbol v) into the lying area of the cubicle house and vice versa (min) (this additional work is only required when AM-CCT is combined with grazing);

$CCTU_w$ = the labour requirement for an unexpected work element w (min);

n_u, n_v, n_w = the frequencies per day of the respective groups of work elements;

m = the frequency per day of rinsing the milking installation and cleaning the milking area;

DALL = disturbance allowance (%);

RALL = rest allowance (%).

The frequencies (n_q, n_w) of groups of unexpected work elements ($HCTU_q$, $CCTU_w$) in the formulas are zero with a flawless running milking process. Therefore, two important conditions need to be fulfilled : (1) the cows have to visit the milking stall voluntarily (without help of the herdsman) and (2) no breakdowns or failures may occur during the milking process. The first condition can probably be fulfilled for the AM-HCT method by using a gate that progresses automatically during milking towards the entrance of the AMS-area thereby forcing the cows to the AMS. The AM-CCT method requires a well-considered and controlled cow traffic to encourage the cows to visit the AMS (Devir et al., 1993).

The second condition is a question of further optimization of the automatic milking process.

Table 7 details the most relevant and workable propositions of the 30 theoretical methods and the physical labour requirements calculated for standard work routines for a two-row cubicle house with 49 cows (comparable with E3 of the observed farm). The labour requirement for supervision and control with the AM-HCT method includes X visits per milking (with X = [number of cows/15] - 1) and one PC control per milking of all the cows, done during the X visits. In the case-study, it amounted to two visits per milking and a labour requirement of 15 minutes per milking. The labour requirement for supervision and control with the AM-CCT includes Y visits per day (Y = determined by the farmer) and a PC control of all the cows, done twice a day during the Y visits. In the case-study, it amounted to three visits and a labour requirement of 30 minutes per day. A PC control requires 0.19 min per cow (see Table 4, point 2). Further, we assumed that unexpected work elements did not appear. To compare automatic milking methods with a conventional milking method, we calculated, by means of simulation, the labour requirement for milking in a 2 x 5 stalls herringbone milking parlour (Table 7). For the milking proper, we used the individual machine milking times of the cows from the observed farm, and the basic times of work elements derived from the task times books of IMAG-DLO (Anonymous, 1973). To calculate the make ready and put away activities with conventional milking, data of the above-mentioned task time books (Anonymous, 1973), which are relevant to a 2x5 herringbone milking parlour, were applied in combination with data of Tables 2 and 3 which are relevant for the layout of the cowshed. Conventional milking is combined with unrestricted grazing, restricted grazing (daytime grazing) and zerograzing.

Not all these methods can be used throughout the year and a combination of the above-mentioned automatic milking methods will be necessary to take into account the period of the year. Therefore, the year is split into three periods : a winter period of 180 days, a transition period consisting respectively of two weeks (winter to summer) and one week (summer to winter), and a summer period of 164 days. Only the AM methods whereby the cows remain indoors (5 with symbol

***Table 7.** The physical labour requirement per day for milking, using different methods*

Conventional milking method (2x5 herringbonde milking parlour)			*Automatic milking with a human-controlled cow traffic*			*Automatic milking with a computer-controlled cow traffic*		
Milking frequency	*Grassland system*	*Labour time (h)*	*Milking frequency*	*Grassland system*	*Labour time (h)*	*Milking frequency*	*Grassland system*	*Labour time (h)*
2	cs or zg	3.11	2	cs or zg	1.41	2	cs or zg	1.15
2	rg 1lp	3.42	2	rg 1sp	1.80	2	rg 1sp	1.57
2	ug	3.72	2	rg 1lp	1.75	2	rg 2sp	1.99
			2	ug	2.08	3	cs or zg	1.15
			3	cs or zg	2.11	3	rg 1sp	1.57
			3	rg 1sp	2.50	3	rg 2sp	1.99
			3	rg 2sp	2.79	f(cow)	cs or zg	1.15
			3	rg 1lp	2.45	f(cow)	rg 1sp	1.57
			3	ug	3.12			

cs = cows stay in cowshed; zg = zerograzing; rg = restricted grazing; ug = unrestricted grazing; 1sp = grazing during one short period of the day (4 h); 2sp = grazing during two short periods of the day; 1lp = grazing during one long period of the day (8 to 12 h); f(cow) = milking frequency related to the individual cow.

cs) can be applied during the winter period. All AM methods (17) are applicable during the transition periods and the summer period. The combination of the methods during the three periods of the year (assuming that the same method is applied during the two short transition periods) suggests 1445 (5x17x17) theoretical combinations available to the herdsman. Table 8 gives some examples ofrelevant combinations of milking methods and grazing systems throughout the year. The figures, calculated with the task time program for automatic milking, are derived from the data shown in Table 7 (= a farm with a two-row cubicle house and 49 cows). Table 8 shows that the introduction of an AMS might result in a labour reduction for milking of minimum 24.0% or 297.7 h/year (comparison between combinations 2 and 14) and maximum 66.1% or 821.3 h/year (comparison between combinations 13 and 14). It is obvious that the combination in which AM-CCT is applied, results in the greatest labour reduction for milking. Remarkable is that combination 1, in which AM-HCT is used throughout the year, even results in a labour reduction of 49.1%. Exactly this combination is employed after the introduction of the AMS on commercial farms. Comparing all the combinations in which only AM-HCT is employed, we can derive that the method in which the cows are milked twice a day and confined permanently to the house, requires the lowest labour input for milking. For the methods where AM-HCT and AM-CCT are combined and for three milkings per day, combination 11 using restricted grazing during one long period of the day applied during the summer and transition periods, scores very well.

4. Discussion and conclusions

According to Belt and Zegers (1984) milking is a light to middle-heavy job for a milker. Automation or semi-automation of the milking process reduces the physical and mental load of the milker (Lundqvist et al., 1993; Sonck, 1992). This study shows that physical work can be reduced

Table 8. *Combinations of milking methods and grazing systems during different periods of the year for a farm with a two-row cubicle house and 49 dairy cows*

Combination	*Milking method and grazing system during*			*Physical labour requirement (h/year)*	*Relative physical labour requirement*
	Winter period	*Transition periods*	*Summer period*		
1	HCT 2x cs	HCT 2x rg 1lp	HCT 2x ug	631.7	50.9
2	HCT 3x cs	HCT 3x rg 1lp	HCT 3x ug	944.0	76.0
3	HCT 2x cs	HCT 2x rg 1lp	HCT 2x rg 1lp	577.4	46.5
4	HCT 3x cs	HCT 3x rg 1lp	HCT 3x rg 1lp	834.5	67.2
5	HCT 3x cs	HCT 3x rg 1sp	HCT 3x rg 2sp	890.6	71.7
6	HCT 2x cs	HCT 2x zg	HCT 2x zg	514.1	41.4
7	HCT 3x cs	HCT 3x zg	HCT 3x zg	771.2	62.1
8	CCT 3x cs	HCT 2x rg 1lp	HCT 2x ug	585.5	47.2
9	CCT 3x cs	HCT 3x rg 1lp	HCT 3x ug	771.0	62.1
10	CCT 3x cs	HCT 2x rg 1lp	HCT 2x rg 1lp	531.2	42.8
11	CCT 3x cs	HCT 3x rg 1lp	HCT 3x rg 1lp	661.5	53.3
12	CCT 3x cs	HCT 3x rg 1sp	HCT 3x rg 2sp	717.7	57.8
13	CCT 3x cs	CCT 3x zg	CCT 3x zg	420.4	33.9
14	CM 2x cs	CM 2x rg 1lp	CM 2x ug	1241.7	100.0
15	CM 2x cs	CM 2x rg 1lp	CM 2x rg 1lp	1192.5	96.0
16	CM 2x cs	CM 2x zg	CM 2x zg	1135.2	91.4

CM = conventional milking in a 2x5 herringbone milking parlour; HCT = automatic milking with human-controlled cow traffic; CCT = automatic milking with computer-controlled cow traffic; 2x and 3x = milking frequency.
cs = cows stay in cowshed; zg = zerograzing; rg = restricted grazing; ug = unrestricted grazing; 1sp = grazing during one short period of the day (4 h); 2sp = grazing during two short periods of the day; 1lp = grazing during one long period of the day (8 to 12 h).

when the AM-HCT method is applied. The physical labour requirement of the milker during the milking proper was only 0.51 min/cow (see Table 1 - 3 : 0.99 min/cow minus time for make ready and put away activities per cow). Ordolff (1972), Ordolff (1989), Sonck et al. (1991) and Clough (1977) mentioned that in traditional milking parlours the practical work routines during milking proper take 0.75 to 2.00 min/cow, depending on the degree of automation. A further optimization of the milking robot will lower the physical labour requirement during milking proper to zero and once the robot is sufficiently reliable the observation activity is also no longer required. AMS independency of human interventions, which amounted already to 90% of the milking time, would then become 100%. Unpredictable interventions, such as breakdowns of the system, fetching of individual cows with a less frequent visiting pattern to the AMS, unsuccessful teatcup attachment, etc. will disturb the daily labour planning and even social activities of the farmer and his family. It might even cause stress to the farmer especially when work of a high priority needs to be interrupted for 'unexpected' milking operations. A high reliability of the AMS and a well-considered plan for the cow traffic will be of major concern.

With the AM-HCT method the milker's job is restricted to preliminary and closing activities. For the observed farm, the make ready and put away activities took 24.75 min/milking (0.48 min/cow/milking) when the cows were indoors and 43.90 min/milking (0.85 min/cow/milking) when the cows had to be collected from the pasture. Maton et al. (1985) mentioned that the labour requirement for the make ready and put away activities of conventional milking amounts to 0.52 and 0.91 min/cow/milking for resp. winter and summer. Therefore, the AM-HCT method will only slightly reduce the labour required for these activities of milking vis-à-vis conventional milking. The greatest labour reduction with this method can be realized during the milking proper. The degree of autonomous working of the automatic milking process will determine the labour savings.

The observations on commercial farms and an experimental farm lead to the development of standard work routines for the make ready and put away activities of the AM-HCT method. The work elements performed during milking were unpredictable and very diverse in nature. A standard work routine for milking proper does not exist with automatic milking. Milking proper without the presence of the milker requires a monitoring system which attracts the attention of the herdsman when something goes wrong. The effects of failures with the AMS milking process on labour organisation and labour requirement need further research. A standard work routine for the AM-CCT method could be derived from AM-HCT. Starting up procedures and cleaning tasks return in the AM-CCT method. A task time program, based on the standard work routines, a calculation model and a visual model of the cow traffic in a total farm system, make it possible to calculate the labour requirement for automatic milking. Within the program, a theoretical approach of the various options with automatic milking results in a large number of working methods with the AMS. The combinations of AM methods (AM-CCT and AM-HCT) with different grazing systems and milking frequencies offer possibilities for different kinds of management styles and farming plans. Calculations show that the AM-HCT can be a workable method on commercial farm level. With this method, farm and grassland management ought not to change thoroughly. Grazing of the animals can still be part of the dairy operation. In addition this method can help to reduce the labour requirement for milking. Reductions with 24.0 to 58.6% were found in our case-study (Table 8).

However, a completely autonomous milking process with a computer-controlled cow routing in the cowshed is the main goal of robotic milking. The AM-HCT method offers some perspectives in this respect. With the AM-HCT method, the farmer cannot be disturbed outside the chosen milking periods by technical failures of the robot or unwanted cow behaviour. The milker has fixed and thus exactly known periods in which he needs to be available for possible interruptions. This method is therefore recommended in the introductory phase of the AMS on a farm. Later on, the herdsman can switch over to the AM-CCT which prevents working at unsocial hours. During the milking proper the farmer can carry out other jobs, preferably in the neighbourhood of the AMS. In the meantime tasks like the care of young stock, maintenance of machines or buildings, cleaning tasks, feeding, etc. can easily be done. The physical load of milking in traditional milking parlours (Stål and Pinzke, 1991; Lundqvist, 1992) can, even with the AM-HCT method, be reduced looking at the work that the milker has to do. Musculoskeletal injuries and occupational accidents can be prevented, but to a lower degree than with the AM-CCT method. The farmer still stays in touch with his animals. Seabrook

(1991) has highlighted that a frequent interaction herdsman-cows can stimulate the milk production level of a herd. Contrary to the AM-CCT in which the layout of the cubicle loose house is very important (Winter et al., 1992; Ketelaar-de Lauwere, 1992b; Metz-Stefanowska et al., 1993), the layout plays a minor role with AM-HCT. The AMS can be installed anywhere in the house provided that a waiting area can be realized. A separated lying and feeding section, a selection unit and gates in combination with a forced routing of cows as mentioned in the research of Ketelaar-de Lauwere (1992a) and Devir et al. (1993) are not really necessary with the AM-HCT method and hence, can be omitted, resulting in a lower investment. However, with the AM-HCT method, the cow's liberty of voluntary visits to the AMS is restricted and access to the AMS is limited to two or three milkings. As a result of the separation of milked cows from the non-milked cows, cows have no access to the feeding gate or to the cubicles for some hours per day. In terms of animal welfare, the AM-CCT method is preferable to the AM-HCT method. Stefanowska et al. (1995) concluded in a study of cow behaviour during the milkings on the above-mentioned first and second farm that herd size and layout of the cowshed are important aspects in relation to an optimal cow traffic. The voluntary traffic to the AMS was better on the first farm (49 cows) than on the second (80 cows) : more cows in the waiting area, higher shifting and less interventions of the milker on the first farm. It might be caused by a smaller herd, higher milk yield and visual contact between cows in the AMS and cows waiting to be milked on the first farm. For large herds (> 60 cows), a division in smaller groups or a higher capacity of the AMS (e.g. three or four milking stalls) will be required to prevent long waiting times for the non-milked cows and to reduce the time that the farmer needs to be in the neighbourhood of the AMS.

Automatic milking with human-controlled cow traffic is a suitable way of milking, not only in the introductory phase of an AMS on a farm, but also when a combination of automatic milking and pasturing is preferred. Even applied throughout the year and with a milking frequency of three times a day, this method results in physical labour savings for milking (37.9%) in comparison with conventional milking. However, automatic milking with computer-controlled cow traffic results in an even larger labour reduction (66.1%). As repair or unexpected troubleshootings were not included in this case-study, the mentioned labour reductions for milking have to be considered as maxima.

The effects of the combinations of automatic milking methods on labour requirement and organisation of the other-than-milking tasks on the farm, including risk analysis, are the subject of further research.

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Appendix A

The following table illustrates that the work elements of the second commercial farm are comparable with those of the described farm (see Table 2).

Table A. *The sequence and basic times of the make ready work elements during morning and evening milking with automatic milking and human-controlled cow traffic on the second commercial farm*

Work element	*Time (min)*	*S.D.* (min)*	*Sequence number Morning*	*Evening*
Entering the dairy	-	-	1	1
Putting the delivery pipeline in the milk tank	0.35	-	2	2
Displacement milker : dairy to milking area	0.15	-	3	3
Placing the milk filter in the pipeline	0.90	0.11	4	4
Starting the system and the computer + control of start	0.55	0.10	5	5
Initializing the robot	0.25	0.08	6	6
Cleaning with water : milking stalls	0.40	0.23	7	17
floor milk pit	0.50	0.33	8	18
slatted floors around AMS	1.35	0.61	9	19
Displacement milker : milk pit to cow exit to pasture	0.20	-	10	
Opening of cow exit door	0.15	0.04	11	10
Driving cows in a large waiting area behind gate I	0.50	0.04	12	14
Placing gate I	0.30	0.21	13	15
Displacement milker : from gate I to gate II	0.20	-	14	
Placing gate II	0.30	0.21	15	8
Displacement milker : gate II to milk pit	0.15	-	16	
Displacement milker : milk pit to gate II	0.15	-		7
Displacement milker : gate II to cow exit	0.35	-		9
Displacement to the cows in the pasture	3.50	0.20		11
Driving cows to the cubicle house	15.00	0.14		12
Closing cow exit door	0.15	0.04		13
Displacement milker : gate I to milk pit	0.15	-		16
TOTAL LABOUR REQUIREMENT (min)			6.25	25.00
TOTAL LABOUR REQUIREMENT (min)(incl. 10% rest allowance + 3% disturbance allowance)			7.08	28.32

* S.D. = Standard Deviation. There are no standard deviations for the basic times of work elements which are calculated (e.g. displacements).

Appendix B

The following table illustrates that the work elements of the second commercial farm are comparable with those of the described farm (see Table 3).

Table B. *The basic times of the put away work elements of automatic milking with human-controlled cow traffic on the second commercial farm*

Work element	*Time (min)*	*S.D.* (min)*
Displacement milker : milk pit to gate of waiting area	0.15	-
Opening gate of waiting area	0.30	0.21
Displacement milker : to milk pit	0.15	-
Protecting the sensors	0.25	0.12
Emptying the milk buffer stock by pressing a button	1.00	0.12
Displacement milker : from milk pit to dairy	0.15	-
Pulling the milk pipeline out of the milk tank	0.35	-
Displacement milker : from dairy house to milk pit	0.15	-
Removing filter	0.75	0.15
Cleaning milk meter of milking stall 1	0.75	0.04
Cleaning milk meter of milking stall 2	0.75	0.04
Cleaning the holder of the filter and the rails of the robot	0.60	0.07
Starting the cleaning program on the terminal	0.30	0.08
Opening one door of each milking stall for cleaning	0.15	0.04
Cleaning milking stall 1	1.50	0.38
Cleaning milking stall 2	1.60	0.64
Cleaning the slatted floors at the entrance and exit of the AMS-area	3.75	1.14
Cleaning the floor of the milk pit	2.30	0.58
Displacement milker : from milking area to dairy	0.15	-
Leaving the dairy	-	
TOTAL LABOUR REQUIREMENT (min)	15.10	
TOTAL LABOUR REQUIREMENT (min)(incl. 10% rest allowance + 3% disturbance allowance)	17.11	

* S.D. = Standard Deviation. There are no standard deviations for the basic times of work elements which are calculated (e.g. displacements)

Chapter 5

Dynamic stochastic simulation of interdependency of automatic milking and labour planning : a model description

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Abstract

A dynamic stochastic simulation model of automatic milking systems (AMS) was built to study the interdependency of the functioning of an automatic milking system and the labour planning of a farmer on operational level. The components of the model are formulated, being the milking robot, the cow selection units, the milking units, the cows and the farmer. The model assumptions are described in the paper. Most parameters of the standard situations are estimated from studies on commercial farms. The model is capable to simulate two working methods with automatic milking systems : automatic milking with a computer-controlled cow traffic and voluntary visits of cows to the milking unit (AM-CCT), and automatic milking with a human-controlled cow traffic and forced visits of cows to the milking unit in fixed periods of the day (AM-HCT). The large number of input parameters of the model offers the possibility to study a wide range of AMS arrangements under various circumstances. Important features are the inclusion of robot failures, the availability of the farmer to the system and the ability to combine automatic milking with pasturing of cows. Effects of unscheduled downtimes of the milking robot on the quality of the milking process can be studied. Quality indicators are defined to judge the milking process and a sensitivity analysis is executed in order to evaluate these indicators. Tests of the accuracy of the model against results with the AM-HCT method applied on a commercial farm suggest an accuracy of within 5%.

Key words : simulation, automatic milking, labour planning, dairy

Abbreviation key : AMS = automatic milking system, **MR** = milking robot, **MU** = milking unit, **SU** = cow selection unit, **CS** = cowshed

1. Introduction

The use of an automatic milking system (AMS), i.e. an arrangement of computerized individual feeding and milking systems in loose housing system dairies, will boost the farmer's satisfaction of work as it will relieve him of the obligatory milking job twice a day and of the short-term control and decisions of milking and concentrates allocation (Devir, et al., 1995c). In addition, the individual feeding and milking regime according to the cows' performance gives the opportunity to fully explore the production of each cow in a herd without any additional labour (Maltz and Metz, 1994). A milking robot (MR), being a part of an AMS, can be implemented as a milking tool on any type of dairy farm. Its effectiveness depends on the management style which reflects the strategic choices of the dairy farmer with respect to herd size, milking frequency, concentrates and forage rationing, grazing, cow housing and farm facilities. This implies that effects on labour organisation have to be investigated under different dairy management styles in order to judge the feasibility of automatic milking systems on these farms with regard to labour time budgeting and labour planning.

The knowledge about the effects of automatic milking on labour requirement and labour planning is still poor which is due to the fact that few systems are yet introduced on commercial farms (Artmann, 1994). Swierstra and Smits (1989) calculated that the total labour requirement per month for a farm with an AMS and with 80 cows would be 70 to 80 hours less than on a dairy farm with traditional milking in a milking parlour. These labour savings are a result of less work for milking and grassland care, but more work for forage harvesting and the young stock. Sonck (1995) described a computational model to determine the labour requirement for milking with an AMS using different working methods and reported that physical labour savings of 37.9% to 66.1% for AMS milking in comparison with milking in a milking parlour are possible. This model was based on observations on two commercial farms. However, work elements related to the occurrence of failures were assumed to be zero. Therefore, the calculated labour savings for milking have to be considered as maxima and the computational model needs to be completed with a labour requirement calculation in case unplanned work elements occur.

The objective of this paper is to describe the components of a dynamic stochastic model that shows the mutual influencing of the AMS performance (including system failures) and the farmer's labour planning on an operational level, under different AMS management strategies with respect to :

- the configuration of the AMS in terms of number of milking units (MU) and cow selection units (SU) and the operating characteristics of the MR in terms of sequence and speed of robot process elements and its performance;
- the cows' visiting pattern to the milking site : computer-controlled cow traffic or human-controlled cow traffic;
- the planned and required availability of the farmer to the system.

The first part of the paper includes a description of the modelling approach, the model assumptions and options. In the second part, a number of quality indicators of the milking process and of work are defined, and a sensitivity analysis is executed in order to evaluate these indicators. A third part deals with tests of the accuracy of the model. The fourth part discusses the applicability of the model.

2. Materials and methods

2.1. General

To study the effects of the AMS on the total farm labour demand and labour planning under different management styles, an extensive research on a wide range of commercial farms is actually required. However, this would be very labour intensive and it even does not cover all conceivable farm management styles. In addition, also on experimental farms, it is not economically feasible to alter the complex system to answer a variety of 'what-if' questions. This would call for another research method. Simulation modelling has been used by several researchers to study the capacity of conventional milking parlours and the labour requirement of the milker (Micke and Appleman, 1973; Burks et al., 1987; Chang and Jones, 1992; Thomas et al., 1994). Parsons (1988) simulated voluntary visits of cows to milking units based on a feasibility study of milking in a feeding box (Rossing et al., 1985). For that purpose, an event-based discrete simulation model was developed and applied in an economic assessment study. Pot and Spetter (1991), Bergmans (1992) and van Elderen (1992) used an object-oriented simulation program to study the occupation of SUs, installed in front of MUs, and of MUs. With respect to the mentioned literature, simulation modelling is a powerful tool to study operational problems. Computer simulation tries to represent a behaviour of a system that reflects the real situation. It is a promising research method to study the functioning of an AMS and the accompanying labour planning.

The modelling approach presented involves the simulation model itself with three input files and two output files (Fig. 1). The input files contain characteristics of the AMS arrangement, the cow herd and the simulation strategy respectively. The output files of a simulation run contain a 'result' file with results per month and per year and an 'event' file with a list of special time events which appeared during one day of each month. Data of the result file are useful in the computational module for labour requirement (Sonck, 1995). Data of the event file are useful in a module for evaluation of the daily labour planning with automatic milking (Sonck et al., 1995). Use of the modules is optional.

The dynamic stochastic simulation model is programmed in PROSIM (Anonymous, 1993a). *Dynamic* (vs. static) means that the model represents a system as it evolves over time. *Stochastic* (vs. deterministic) points to the use of random input components. PROSIM is an object-oriented simulation tool for a Personal Computer. It delivers a framework for modelling, simulation and validation. The object-oriented approach of modelling with classes of objects (cow, selection unit, milking unit, cleaning unit) enables the system to be configured during the simulation. A class lists the variables and describes the process of the activities of objects in that class. It also describes the relations between objects (cow and milking unit) and the dynamic aspects of the system in time (duration of milking). Each object has its own characteristics (variables) and follows the process in its

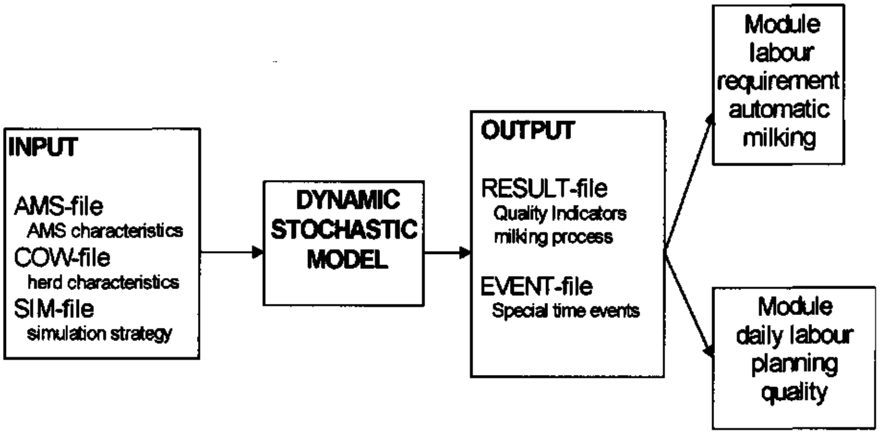


Fig. 1. Schematic overview of the modelling approach. Information flow between the models is indicated by arrows. Use of the modules is optional

own way. The language handles discrete processes (discrete time advance : cow starts/ends milking) and continuous processes (continuous change of certain variables : milk yield as function of the time of the day).

In the following, we describe the assumptions and possibilities of the model simulating the functioning of the AMS in relation to the daily labour planning.

2.2. Configuration and usage of the automatic milking system

The AMS has milking, feeding and cow traffic control functions. There are several ways to integrate these functions in the dairy farm. This model is able to simulate three different configurations :

(1) One or more cow selection units (SU), with or without a feeder dispenser and installed in front of the MUs. With the SU it is possible to send a cow back to the cowshed when a minimum expected milk yield or minimum milking interval is not achieved, or to guide the cow, via gates, to a free MU. One or more milking units (MUs) installed in line are served by one MR. The MU can be provided with or without a feeder dispenser. This configuration is comparable with those applied in the research of Devir et al. (1993a), Devir and Metz (1994), Devir et al. (1995a,b,d).

(2) No cow selection units are installed. Cows collected in a waiting area during fixed periods of the day immediately get access to the MU as soon as it becomes free (Sonck and Donkers, 1995). MUs and MR are configured as in (1).

(3) The same arrangement as in (1) and (2) but with a two-sided design : MUs on two sides and a linear moving and rotating MR.

There are two working methods included in the dynamic stochastic model to implement the mentioned AMS configurations on a dairy farm defined by Sonck (1995) as :

(1) Automatic milking with *a computer-controlled cow traffic* (AM-CCT) which implies voluntary cow visits to an AMS consisting of SUs and MUs equipped with an MR. Cow traffic is controlled by the cow selection units and by a dairy control and management system that makes milking and feeding decisions (Devir et al., 1993b). The AMS is almost 24 h a day available to the cows, except during the cleaning of the installation (or during the grazing periods, if any).

(2) Automatic milking with *a human-controlled cow traffic* (AM-HCT) which requires the farmer's assistance to collect the cows from the pasture or from the loose housing system in front of the AMS and supposes milking during fixed periods of the day. During such a period, defined as *milking time window*, all cows are milked by the system. The milking robot replaces only the milker in the parlour. The starting time of the first milking time window is an input parameter. The interval between the milking time windows is determined by the milking frequency : the interval is 24 h divided by the milking frequency.

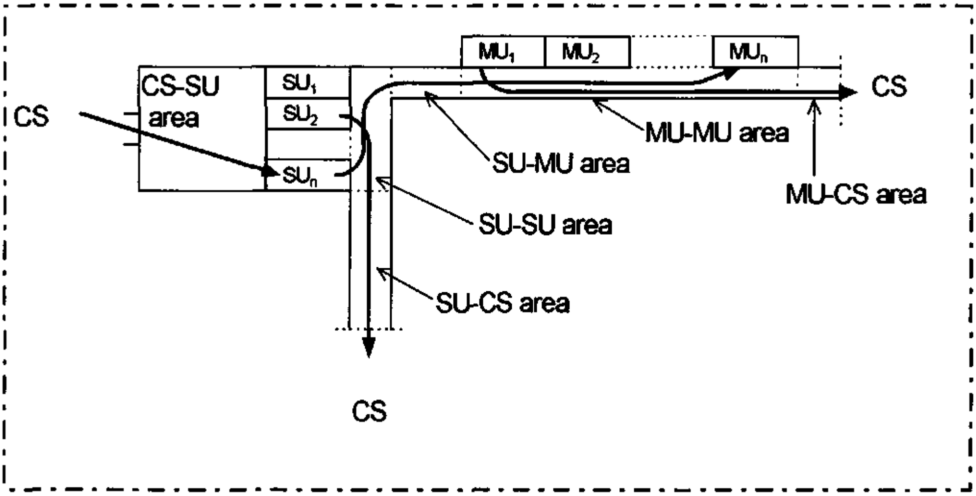
2.3. Cow routing

The applied cow routing depends on the chosen working method for automatic milking. Fig. 2 gives a schematic representation of the cows' movements for the AM-CCT with SUs and MUs as assumed in the model. The cow presents itself for selection after a calculated presentation interval. The cow proceeds from the cowshed (CS) to a free SU (through the CS-SU area) where it is identified and starts concentrate consumption, if any. After eating concentrates, the cow has to wait for the permission to leave. In the SU it is checked whether the cow fulfils the selection criterion and can be milked or not. If the cow needs to be milked, it proceeds to a free MU and passes the SU-SU area and the SU-MU area. If the cow is not selected for milking, it returns to the CS through the SU-SU and the SU-CS areas. A milked cow leaves the milking stall and returns to the cowshed. It passes the MU-MU and MU-CS areas.

As more SUs and MUs can be installed, a priority status to proceed is needed. Three possibilities for this priority status are included in the model, viz. : (1) The 'first in, first out' principle (FIFO) : the first cow that arrives in the queue of requests to proceed is the first to be served. (2) The efficient use of the MU : preference is given to requests of cows to leave the MU. (3) The efficient use of the SU : preference is given to requests of cows to leave the SU.

Table 1 shows the use of the walking areas when a cow is moving from one place to another. Areas that are *used* during a cow movement exclude other cow movements in that area. *Blocked* areas cannot be entered during a cow movement and more cows can block the same area. For example, a cow can walk from an SU to the CS at the same moment as another cow walks from the MU to the CS. An area that is *free* during a cow movement can be occupied by another cow.

The milking priority of cows is based on one of the following two principles : (1) The 'first in first out' principle : the first cow in an SU that is selected for milking and has completed its concentrates consumption is the first to get access to a vacant MU of the AMS. (2) The milk yield : the cow with the highest milk yield, that is selected for milking and has been fed concentrates in an SU, is the first to get access to a vacant MU.



SU = selection unit; MU = milking unit; CS = cowshed

Fig. 2. *Schematic representation of the cow movements in an AMS arrangement for the simulation of automatic milking with a computer-controlled cow traffic*

Table 1. *State of walking areas for the four cow movements with AM-CCT (See Fig. 2)*

COW MOVEMENT	*WALKING AREAS*					
	CS-SU	*SU-SU*	*SU-CS*	*SU-MU*	*MU-MU*	*MU-CS*
CS → SU	used	free	free	free	free	free
SU → CS	free	used	used	blocked	free	free
SU → MU	free	used	blocked	used	used	blocked
MU → CS	free	free	free	blocked	used	used

Remark :
used = one cow allowed; blocked = not in use or more cows block the same area
SU = selection unit; MU = milking unit; CS = cowshed.

With the AM-HCT method, the cow routing is comparable with that of AM-CCT. The total herd of cows however is presented to the AMS in two or more milking time windows of the day. The end of a milking time window coincides with the end of milking the last cow in the milking order. Outside the milking time windows, the AMS is not available to the cows. Rose and Labussière (1977) and Rathore (1982) mentioned a high correlation between the sequence of the cows entering a milking parlour and their milk yield. Dietrich et al. (1965) and Willems and Lampo (1964) reported the contrary, but mentioned, just like Klijn and Nieuwenhuysen (1964), the existence of a group of leaders and stragglers. The milking order of the remaining group was variable. Stefanowska (pers. comm.) observed the same for an AM-HCT applied on commercial farms. For the model, we combine two of the mentioned scientific findings : the correlation between milking order and milk yield, and the existence of a group of leaders and stragglers. For that purpose, the cows are classified in descending order of their expected milk yields. Two groups, each representing approx.

25% of the herd and composed of respectively the leaders and the stragglers are milked in that order. The cows of the remaining group are milked in an order determined by a random drawing from a uniform distribution.

In reality, no SUs are used with the AM-HCT method. The cows immediately enter the MU-MU area when an MU is free. To exclude the SUs as limiting factor in the milking process and to approach the reality as much as possible, a simulation for this method has to be executed assuming all process times related to SUs to be zero. To maintain the mentioned milking order one SU can be used or the priority status for proceeding and for milking can be governed by the FIFO-rule.

2.4. Presentation of cows to the system

Presentation intervals of cows, i.e. the duration between two successive presentations of a cow at the SU occur only in the AM-CCT method. Parsons (1988) presented a formula for presentation interval duration derived from a cumulative frequency distribution. This distribution was based on recorded intervals in an experiment of Rossing et al. (1985) where cows were milked in a feeder box. The weak point in this formula is that the maximum value for the presentation interval is not fixed, but approaches infinity for a random number close to 1. This will never happen in reality however. In addition, behavioural studies showed that cows visit the AMS more during the day than during the night (Ipema et al., 1987; Winter et al., 1992) and that there are individual deviations from the average visiting pattern (Ipema et al., 1987; Kremer, 1993). The presentation interval is time and cow dependent. Therefore, a single mathematical formula that describes the presentation interval for a total herd is not a suitable method.

In the model, we used the approach of van Elderen (1994) who tried to fit probability distributions to data of presentation intervals of 16 cows in a period of 9 days for an AMS, derived from a research of Devir et al. (1993a). In this study, the cows were split up into a group of high frequent and one of low frequent visitors to the AMS. The difference between both groups is arbitrarily made on the basis of the length of the interval between two successive visits to an SU. A *short* interval visit is a visit which occurred within less than two hours since the last visit to an SU, otherwise it is a *long* interval visit. The low frequent visiting cows have less than 25% of short interval visits, otherwise they are classified as high frequent visitors to the AMS. The experimental data of each group were characterized by a composition of two Beta distributions, one for short interval visits (0 to 2.25 h), and another for long interval visits (2 to 18.5 h) and by the relative frequency of the short intervals. Wilcoxon's Rank-sum Test confirmed the hypothesis that the composite distributions are equal to the experimental frequency distributions for the two categories (at the 0.05 level). In the model the fitted Beta distributions are characterized by a mean and a standard deviation and by a lower and upper bound of the short and long intervals. The herd is characterized by low frequent and high frequent visitors to the AMS with a known fraction of each category. Table 2 shows the parameters of both composite distributions for each category, as selected for the standard simulation run, and the general characteristics of a Beta distribution. This results in the probability density functions for the low frequent and the high frequent visitors, shown in Fig. 3.

Table 2. *Parameters of Beta distribution functions to represent the experimental frequency distributions of presentation intervals of Low (LFC) and High Frequent visiting Cows (HFC)*

Category	*Fraction*	*Mean (h)*	*Deviation (h)*	*Lower bound (h)*	*Upper bound (h)*
LFC with					
short interval duration	0.17	0.75	0.47	0.00	2.25
long interval duration	0.83	7.18	3.40	2.00	18.50
HFC with					
short interval duration	0.46	0.65	0.48	0.00	2.25
long interval duration	0.54	7.00	3.00	2.50	18.50

Characteristics	*Mathematical representation of a Beta distribution*
Probability density function	$f(x) = \begin{cases} \dfrac{x^{\alpha_1 - 1}(1-x)^{\alpha_2 - 1}}{B(\alpha_1, \alpha_2)} & if\ 0 < x < 1 \\ 0 & otherwise \end{cases}$
Beta function	$B(\alpha_1,\alpha_2) = \int_{\alpha_1}^{\alpha_2} x^{\alpha_1 - 1}(1-x)^{\alpha_2 - 1}\,dx$
Mean	$\dfrac{\alpha_1}{\alpha_1 + \alpha_2}$
Variance	$\dfrac{\alpha_1\alpha_2}{(\alpha_1 + \alpha_2)^2(\alpha_1 + \alpha_2 + 1)}$
Mode	$\begin{cases} \dfrac{\alpha_1 - 1}{\alpha_1 + \alpha_2 - 2} & if\ \alpha_1 > 1, \alpha_2 > 1 \\ 0\ and\ 1 & if\ \alpha_1 < 1, \alpha_2 < 1 \\ 0 & if\ (\alpha_1 < 1, \alpha_2 \geq 1)\quad or\ if\ (\alpha_1 = 1, \alpha_2 > 1) \\ 1 & if\ (\alpha_1 \geq 1, \alpha_2 < 1)\quad or\ if\ (\alpha_1 > 1, \alpha_2 = 1) \\ does\ not\ uniquely\ exist\ if\ \alpha_1 = 1, \alpha_2 = 1 & \end{cases}$
Range	[0,1] Remark : a beta random variable X on [0,1] can be rescaled and relocated to obtain a beta random variable on [a,b] of the same shape by transformation a + (b - a)X.

The above-mentioned determination of presentation intervals does not consider the occurrence of a diurnal visiting behaviour pattern that is characterized by activity during the day and rest at night, as reported by Nuber (1989) and Winter et al. (1992) in simulation studies of automatic milking. Therefore, the relative frequency of time that cows gain each hour of a 24 h span to meet their presentation interval can be set. It enables to create a cow behaviour pattern with more frequent visits to the AMS during certain hours of a day.

The *milking frequency* is controlled by the selection criteria in the SU and by interventions of the farmer. The acceptance for milking in the model can be based on : (1) a preset minimum milking

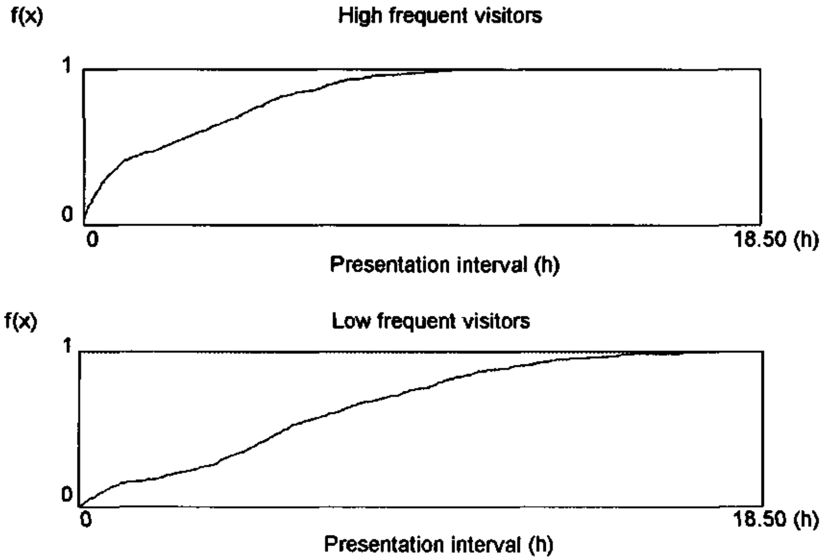


***Fig. 3.** Probability density functions for the low and high frequent visiting cows*

interval since last milking, or (2) a preset minimum expected milk yield since last milking or (3) a minimum milking interval that is function of the lactation stage or (4) a minimum expected milk yield that is function of the lactation stage. Cows exceeding a preset maximum milking interval are supposed to be brought and guided to the system by the farmer.

With AM-HCT, all cows are presented to the system during fixed periods of the day. Here, the presentation interval to the SU is determined by the herdsman, i.e. the milking time windows.

2.5. Herd size and structure

The herd size will, in combination with the milking frequency, determine the required SUs and MUs, and is an input parameter of the model. Based on three field tests, Devir (1995) recommends a herd size of up to 80 cows, which are milked 3 to 5 times a day, to achieve the maximum efficiency of an AMS with two MUs and with voluntary visits to the SUs. This implies that large herds (more than 80 cows) need to be divided into subgroups of 40 to 80 cows, according to milking frequency preference or production potential, and milked on different MR sites on the farm. If grouping is preferred, each group with its characteristics requires a separate simulation run with the model.

The structure of a herd depends on the lactation stage of each cow. This information is determined by the chosen calving pattem. The calving pattems applied in the model are derived from van Arendonk (1985) and Mandersloot and van der Meulen (1991). Three calving patterns are included in the model : non-seasonal, spring and autumn calving. However, the distribution of the calvings over the months can easily be adapted to the user's wishes. The herd structure is also determined by the age distribution of the herd and depends on the culling rate which is derived from

Mandersloot and van der Meulen (1991). Six age groups, from age two to seven years, are considered. The age group of seven years covers all the cows of seven years and older. We assume the first calving of a cow to be at the age of 2 and the calving interval to be one year exact. Four culling rates are considered : 20%, 25%, 30% and 35%. Initializing a cow in the model begins with assigning a lactation day and age to a cow, drawn randomly from distributions based on the chosen calving pattern and age distribution.

2.6. Lactation production and daily milk yield

The cow's daily milk yield is influenced by effects such as age and season of calving, stage of lactation, herd and number of days open (Dommerholt, 1975; Danell, 1982; Bar-Anan and Soller, 1979). To predict the shape of the lactation curve, the functions of Wilmink (1987) were used. Wilmink (1987) analyzed test-day records of 14 275 purebred Dutch Friesians by generalized least squares. Functions of days in lactation and age (in months) were fitted to the age differences for different lactations stages. Ten age classes were defined, corresponding to 22-24, 25-27, 28-32, 33-37, 38-44, 45-56, 57-68, 69-92, 93-104 and more than 104 months as age of calving. The R^2 for the first, second, third and higher parity cows was 99.9, 87.2, 95.5 and 99.7% respectively. The function of the lactation curve is described by :
where :

$$milk\_yield\_rate\_wilmink(x) = level(x) + def(x, t) + season\_effect(x) \qquad (1)$$

milk_yield_rate_wilmink(x) = milk yield rate (kg/d) on day x in lactation, calculated according to Wilmink (1987);

level(x) = level of milk yield per day for age class 1 (22-24 months at calving) at day x in lactation;

dif(x,t) = difference in milk yield per day at day x in lactation and for cows older than 24 months (t);

season_effect(x) = correction factor for seasonal effect based on six periods of calving and on day x in lactation.

The *standard_cow_production* is defined as the milk yield rate (kg/d) on day 50 in the lactation of a cow with an age of 77.8 months (age class 8) at calving and with calving in February. Entering these data in Eqn. (1) results in 29.072 kg/d which we define as the *wilmink_cow_production*. The milk yield rate of a cow with a *standard_cow_production* which differs from the *wilmink_cow_production* is in the model derived with the following equation :

$$milk\_yield\_rate(x) = \left(milk\_yield\_rate\_wilmink(x)\right)\frac{standard\_cow\_production}{wilmink\_cow\_production} \qquad (2)$$

where :

milk_yield_rate(x) = milk yield rate (kg/d) on day x in lactation;

wilmink_cow_production = milk yield rate (kg/d) of a cow, 50 days in lactation aged 77.8 months at calving and with calving in February, calculated with Eqn. (1);

standard_cow_production = milk yield rate (kg/d) of a cow, 50 days in lactation, aged 77.8 months at calving and with calving in February, input data of the model.

Eqn. (2) enables to calculate the *milk_yield_rate(x)* of cows with production levels that differ from those involved in the calculations of Wilmink (1987).

The expected milk yield of an individual cow is calculated as follows :

$$milk\_yield = milk\_interval \cdot milk\_yield\_rate\ (x) \tag{3}$$

where :

milk_yield = expected milk yield (kg) for a cow and for a milking;

milk_interval = the time interval (d) between the previous and present milking of a cow.

The milking time of a cow and for a milking is calculated with the formula of Clough (1977) who derived a relationship between the mean machine milking time and the mean milk yield in kg/cow, for 28 herds. The equation is :

$$milking\_time = 2.75 + 0.207 \cdot milk\_yield \tag{4}$$

where :

milking_time = machine milking time of one cow (min);

milk_yield = expected milk yield (kg) for a cow and for a milking.

Ipema and Benders (1992) found that the duration of machine milking increased with about 40% when the milking frequency was raised from 2 to 3 times daily. Zipper (1990) found increases of 24%. Formula (4) results in an increase of 20 to 40% for milk yields of 40 to 7 kg/d respectively, when the milking frequency is raised from 2 to 3 times daily. The results obtained from formula (4) are comparable with those of the mentioned research.

2.7. The performance of the milking robot

Teatcup attachment of the cows and robot request

A successful teatcup attachment of cows by the robot depends on cow characteristics (such as cow behaviour in the milking stall, shape of the udder, teat directions, etc.) and the ability of the robot. The cows are categorized as suitable (A), partially suitable (B) or unsuitable (C) for automatic teatcup attachment depending on their success rate for teatcup attachment viz. always, sometimes and never within a preset maximum time. The fraction of times a B-cow behaves as an A-cow has to be imported in the input files and it is a priori not fixed which cow owns this feature. The number of attachments is randomly drawn from the interval [1, *max*] with *max* defined as the maximum number of attachment trials. The maximum time for attachment is determined by *max* and the process time per attempt. Field test results and milking robot suppliers indicate a teatcup attachment duration of 0.5 to 3 min (Hogewerf et al., 1992; Frost et al., 1993; Rossing et al., 1994). Devir et al. (1995a) suggest that for up to 2-3 min the process of attachment acts as a stimulation factor on the udder, which might cause the milk yield to increase. According to Rasmussen (1994) a longer attachment time might lead to a higher amount of residual milk and a decrease in milk yield. An attachment within two minutes was therefore adopted as standard in the model.

The robot is at a certain moment requested to move to an MU and to attach the teatcups to a cow. This moment is optional in the model and can be : (1) when the cow leaves an SU to walk to an MU, (2) when a cow arrived at an MU or (3) when the cow is positioned in an MU, i.e. when the cow has entered the MU, the length of the milking stall is adjusted to the size of the cow (done by moving the feed dispenser in the MU forward or backward), and the cow is identified.

If more cows require the robot for attachment, the robot requests are handled so that cows with the highest milking priority are served first. The cows which fail teatcup attachment are collected in a separation area. These cows are milked when the farmer is available to supervice and when the system is free. For AM-CCT, this is when SUs and MUs are free and for AM-HCT, when the last cow of a milking time window has been milked.

System failures

System failures may be caused by robot component failures or cow-induced disturbances or exceptional events such as lightning (Street et al., 1994). Sonck (1995) reported a list of the most repeating work elements related to 'assistance with a milking robot'. The main sources of failures were problems related to teatcup attachment and caused by component failures of the milk rack arm, by the sensors or by software problems. These data were insufficient to fit a distribution which might describe the occurrence of failures.

The most important source of randomness for many manufacturing systems is that associated with machine breakdowns or unscheduled downtime. The exponential distribution is the only continuous distribution with the memoryless property (Ross, 1989) and therefore suitable to simulate machine breakdowns (Law and Kelton, 1991). Incorporation of robot failures during simulation is optional in the model. Few data on breakdowns of the AMS are available. As we assume the occurrence of a robot failure to be independent from robot failures that appeared in the past, an exponential distribution is applied to simulate the occurrence of robot failures. The expected time (in hours) of failure-free operation of the robot is used as mean value for the exponential distribution. The milking robot is working until its total accumulated *processing time* since the last downtime, reaches a random value generated from this distribution.

No data of machine downtime (or repair time) are available to fit a distribution. If very little is known about the random variable other than its range, Law and Kelton (1991) advice the use of a uniform distribution. In the model, a uniform distribution with a lower and an upper bound is used for establishing the repair time for robot failures. Two cases are distinguished : the farmer does the repair himself or it is carried out by a service technician of the robot supplier. In the latter case, the system might be inoperative during a longer period. If the farmer is able to do the repair and is available when the system fails, the travel time for the farmer is supposed to be zero. If the farmer is unavailable, the system remains inactive until the repair is done.

2.8. Cleaning the milking installation

The cleaning schedule depends on the applied method. For AM-CCT, the number of cleanings and the duration of cleaning are input parameters. The milking units can be cleaned simultaneously (interval is zero), or an interval can be foreseen between the cleanings of the various milking units so as not to block all MUs at the same time. The length of the interval is an input parameter of the model.

Verheij (1992) found cleaning interval settings of 24 and 12 h to be insufficient to meet the requirements for the bacteriological quality of milk. The optimization of the sanitary design of milk transfer equipment and the use of refrigerated cooling of milk immediately after production may extend the cleaning intervals up to 12 h. For the standard situation in the model, we accept three cleaning routines per day per MU and a simultaneous cleaning of all MUs. Cleaning time amounts to 0.75 h.

In the AM-HCT method, the number of cleanings is related to the number of milking time windows, i.e. the chosen milking frequency. A cleaning of the system is done at the end of a milking time window, namely when all cows are milked, including the separated cows which are handled by the farmer. A delay in the milking time window will cause a delay in the cleaning of the AMS.

2.9. Concentrates supplementation

Concentrates supplementation in SUs and MUs has three goals : (1) attracting cows to the MU or SU, (2) automatic distribution of feed to individual cows according to their performance and (3) keeping cows calm in the MU or SU. Although, it should be avoided that concentrates supplementation in SUs and MUs becomes a limiting factor of the AMS capacity, it is included in the model. It provides a tool to estimate the maximum amount of concentrates that can be administered without limiting the capacity of the AMS.

The amount of energy is expressed in Dutch feed units for lactation (VEM) : one VEM unit equals 6904 kJ net energy (van Es, 1978). The intake and energy content of feedstuffs are expressed on dry matter basis. The required daily VEM intake for sustainment and for milk production is derived from the cow model of Hijink and Meijer (1987). The daily VEM intake from forage however is derived from experimental data (Anonymous, 1993b). The daily VEM intake from concentrates is the difference between the total VEM intake per day and the VEM intake per day from forage. The total daily amount of concentrates is split into two fractions consumed in the SU and MU respectively. If no concentrates are needed, a small amount (candy) can still be supplemented in the SU (Devir et al., 1995b). The use of concentrates is optional in the model.

2.10. Daily labour planning of the farmer with respect to the AMS

A labour planning that takes into consideration the functioning of the AMS will be needed, especially in the early days of working with an AMS and when failures occur. When planning his daily chores the farmer should consider where, when, how long and at what distance from the AMS a task is being done. He will also have to set priorities where some tasks or activities are concerned. In general, the time of the farmer can be allocated to milking job, non-milking jobs, personal and social activities (Fig. 4). Two kinds of operations can be distinguished : the planned and the unplanned milking operations. The planned milking operations for AM-CCT and AM-HCT and their respective labour requirements are described in Sonck (1995). The unplanned milking operations include (1) the repair of failures, (2) the milking of separated cows and (3) bringing cows to the MU that exceed a maximum milking interval. The farmer's daily planning of his milking operations will affect AMS functioning. The good or bad functioning of the AMS will determine the occurrence of unplanned milking operations which can disturb the daily planning. On the other hand, the daily planned jobs where the farmer cannot be disturbed and is unavailable to the system, will delay the unplanned milking operations, and therefore negatively affect the AMS functioning.

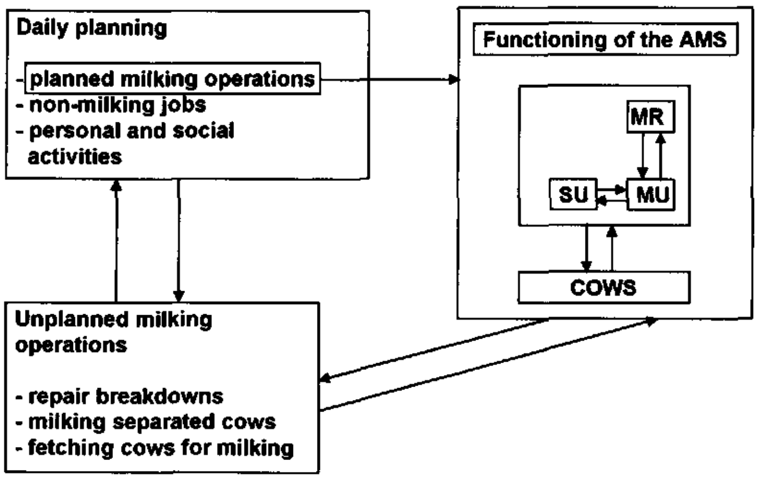


Fig. 4. Interrelations between the planned and unplanned operations and jobs of the farmer and the functioning of the automatic milking system (AMS = automatic milking system; SU = selection unit; MU = milking unit; MR = milking robot)

Unplanned milking operations

The labour requirement for an unplanned milking operation and the moment of its occurrence can be derived from the simulation model. As the farmer will not always be available (present on the farm) or refrains from executing unplanned milking operations, two schedules which demonstrate the availability of the farmer to the system during a 24 hour period are introduced in the model : one schedule for repairs and one for milking separated cows. Each schedule consists of a maximum of

12 intervals (= *farmer windows*) each defined by a starting time and a duration. If the farmer is available at any moment of the day, only one farmer window, starting at 0 h (midnight) and lasting 24 h needs to be defined. The remaining eleven farmer windows have then a starting time at 0 h and a duration of 0 h. In this case it is assumed that the farmer remains in the vicinity of the AMS during the whole day.

System breakdowns, due to robot component failures or cow-induced disturbances, and the unavailability of the farmer to intervene at the same time will halt the system and upset the milking process. The moments that cows exceed a preset maximum milking interval and have to be brought to the MU, are stored in the 'event' file and are used for labour planning and labour requirement calculations.

Planned milking operations

The scheduling of daily returning milking operations which temporarily block the system will affect the AMS functioning. The model offers a tool to plan these operations. For AM-HCT, the milking operations are associated with the fixed milking periods : some operations are carried out before and some after milking (Sonck, 1995). As milking with AM-CCT is based on voluntary visits of cows to the system and milking and feeding decisions are made by a dairy control and management system, the farmer has more freedom to plan his milking operations related to this method. Some examples of planned milking operations incorporated in the model follow :

(1) Cleaning of the milking installations and the milking parlour requires the help of the farmer. For reasons of milk quality, the milking installations need rinsing and cleaning within an interval of maximum 12 h (Verheij, 1992). To plan this operation during more social hours of the day, the start and end of a *time window for cleaning* can be defined in the model. The required cleanings are then regularly spread over this time window, instead of over a period of 0 to 24 h.

(2) Grazing gives rise to a cow traffic from and to the cowshed, which requires the farmer's help for herding. Labour requirement is calculated with the computational model of Sonck (1995). Grazing however upsets the system and prevents cows of presenting themselves to the AMS. The start and end of a *time window for pasturing* can be imported in the model and will affect AMS capacity. Although the AMS is blocked during a pasturing time window, cows in the SU, MU or cows handled as separated cows can still make use of the AMS when this time window starts.

3. Definition of quality indicators

A simulation output delivers two files : a result file and an event file. The result file is a report with statistical data of the simulated days of each month and a list of statistics of cow data, selection units, milking units, the occupation of the farmer with unplanned milking operations and other components. Special time events are stored in the event file. The simulation output is used for the evaluation of the labour planning vis-à-vis automatic milking (Sonck et al., 1995). The simulation is illustrated to show the behaviour of the model. The state of the SUs, MUs, the farmer and the robot are visualized on the PC screen. Individual machine milking time, milk yield, amount of supplemented concentrates and number of waiting cows in front of the system are some examples of data shown in the animation. It is an efficient instrument to check the validity of the model as a description of the process dynamics in reality.

An optimal use of the system supposes an AMS that serves as many cows as possible and guarantees an individual milking regime directed to a maximation of the milk production with a minimum number of milkings and a minimum involvement of the farmer. This might be reached under different AMS management strategies. To judge these and the influence of labour planning on AMS functioning or vice versa, some quality indicators related to the cow, the MR, SUs and MUs, and the farmer are needed. We first give a view on the relation between the processes of the components of the simulation model as an aid to define the quality indicators. Fig. 5 shows a simplified schematic presentation of the processes of the components COW, SU, MU and ROBOT, as programmed. The arrows are time events pointing to a moment and the ellipses are activities pointing to a duration. The whole process that a cow is subjected to can be followed via the bold arrows. The flow chart can be applied to the AM-CCT method as well as to the AM-HCT method.

Too long waiting times in front of and in the SU or MU might discourage cows visiting the AMS and, as a consequence, increase the manual work for the farmer. Therefore the following monthly averages and maxima of cow waiting times are selected as quality indicators (Fig. 5) : the time between presentation to and entering the SU (A $\rightarrow$ B); the time between end of eating concentrates and the allowance to walk to the MU or cowshed (D $\rightarrow$ G1 or D $\rightarrow$ G2); the waiting time for teatcup attachment (I $\rightarrow$ L); the waiting time for milking (B $\rightarrow$ L) and the time that a cow occupies the total system (B $\rightarrow$ CP1). SUs, MUs and the MR have to be used optimally. The time (% of 24 h) that an SU is in use (B $\rightarrow$ SP1), an MU is in use (E $\rightarrow$ MP1), an MU is occupied (H $\rightarrow$ N) and the robot is in use (RP2 $\rightarrow$ RP1) are therefore revealing indicators. The milking frequency can be derived from the maximum and average milking interval for a certain month, the yearly average milking interval and the minimum, the maximum and average number of MU visits. The farmer's involvement in the milking process is given by the time (1) the farmer is unavailable, (2) repairs failures, (3) handles separated cows, (4) brings cows to the MU that exceed a maximum milking interval, (5) is available but has no work and (6) works outside the planned farmer windows.

The AM-HCT is characterized by two or more milking time windows per 24 h. During a milking time window, all cows of the herd are milked. As there is always a cow available for milking the maximal capacity of the MR can be derived. Therefore, two quality indicators are added for the AM-HCT method : the yearly average milking time window duration (h/day) and the milking time window duration (h/day) of a certain month. This duration indicates the time that the farmer has to be in the neighbourhood of the AMS and is instrumental to calculate the capacity of the MR in terms of number of milked cows per hour.

4. Confidence interval of the quality indicators

The simulation model is built to study how the quality indicators behave when different system parameters are changed. Hence, the responses of different simulation experiments should reflect no noise but the true effects of changing parameters. While running the simulation model, random numbers are generated at various moments. In order to distinguish significant from not significant differences in output data of the model, the influence of the random generator has to be investigated first. Therefore, we calculated the average, standard deviation and the 95% confidence interval (Student's statistic with n - 1 degrees of freedom) for the quality indicators of the milking process under standard conditions, using 10 independent simulation runs. Only the initial number of the random generator was changed. Tables 3 and 4 show the results of these sensitivity analyses for AM-CCT and AM-HCT. The average milking time window duration for a year and the month of April are specific indicators for the AM-HCT method and are therefore included in Table 4. The *confidence interval* can easily be converted into a hypothesis test (Kleijnen, 1987). A smaller variance in the quality indicators results in a narrower confidence interval and an increased probability in detecting effects of changed parameters. Results of simulation runs have to be judged with the 95% confidence intervals of Tables 3 and 4 in mind.

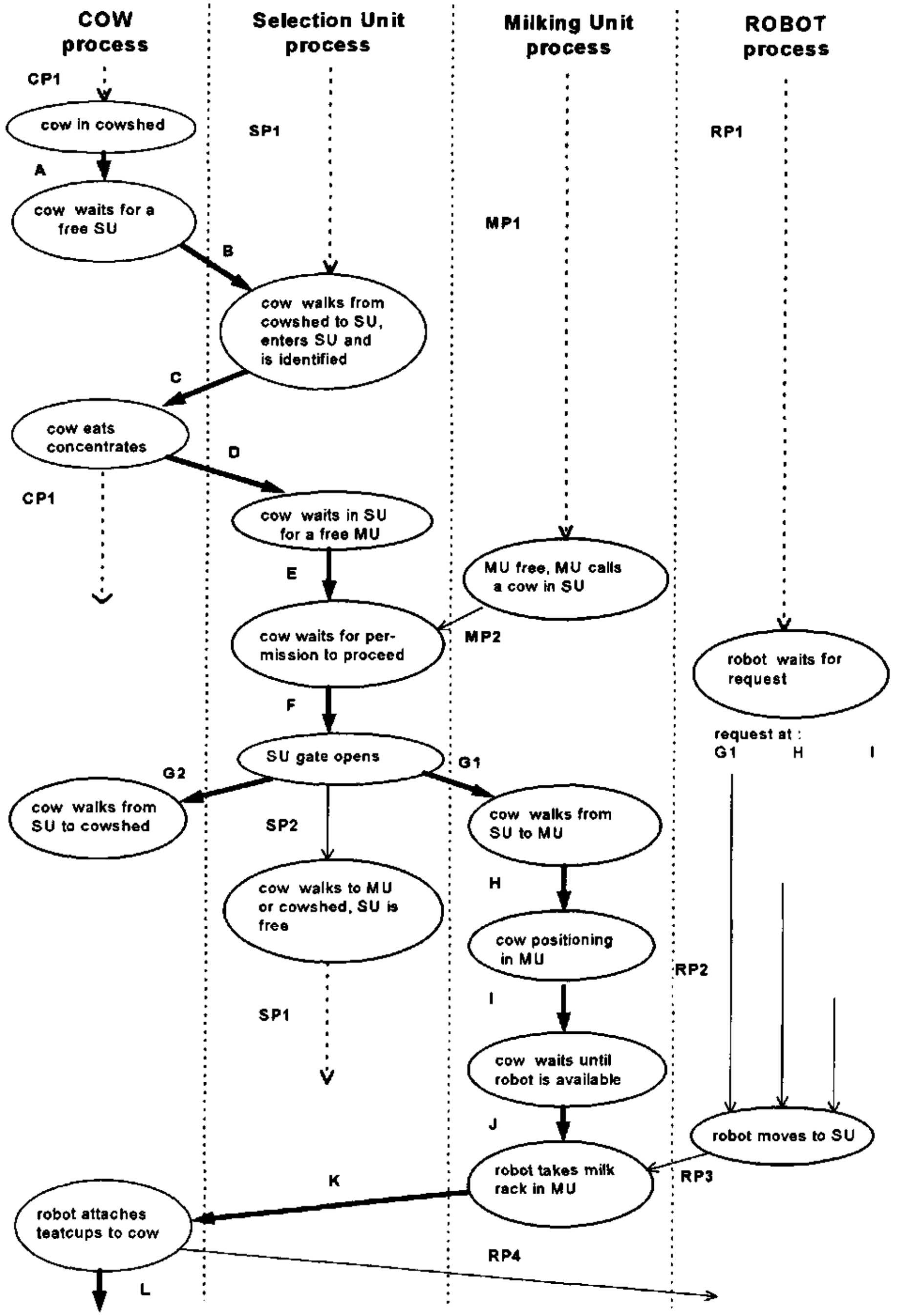
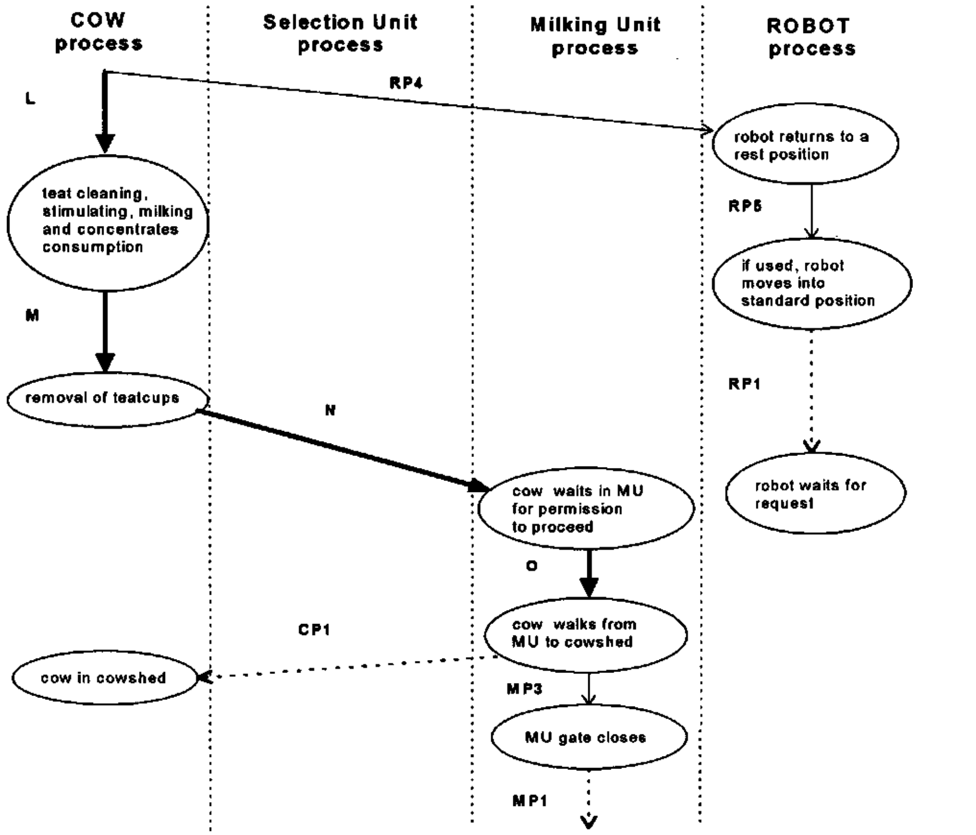


Fig. 5. Simplified schematic representation of the AMS simulation model showing COW, Selection Unit (SU), Milking Unit (MU) and ROBOT processes. To be continued



Key to the figure :

Arrows : time events pointing to a moment
Ellipses : activities pointing to a duration
Bold arrows : follow the cow in all the processes
Fine arrows : are specific to one process (COW, SU, MU or ROBOT)
Dotted arrows : the process starts or restarts

Arrows :
A = presentation of cow to SU
B = cow is allowed to enter the SU
C = cow starts eating concentrates
D = cow finished eating concentrates
E = MU becomes available to cow in SU
F = cow is allowed to walk
G1 = SU gate opened and cow exits SU to walk from SU to MU
G2 = SU gate opened and cow exits SU to walk from SU to cowshed
H = MU gate closed after the cow arrived and entered the MU
I = end of cow positioning
J = start of taking milk rack in MU by robot
K = end of taking milk rack in MU by robot
L = teatcups are attached to teats; teat cleaning, stimulating and milking starts
M = end of milking
N = end of milk rack removal
O = cow is allowed to walk from MU to cowshed
CP1 = start or restart of the process when cow arrived in cowshed
SP1 = start or restart of SU process, SU is free
SP2 = SU gate opened (SU2 = G1 = G2)
MP1 = start or restart of MU process, MU is free
MP2 = cow becomes available to MU (MU2 = E)
MP3 = cow arrived in cowshed
RP1 = start or restart of ROBOT process, ROBOT becomes free (in standard position)
RP2 = robot request to move to MU. It depends on the chosen option for 'robot request', i.e. robot request at moment G1, H or I.
RP3 = robot arrived at MU (RB3 = H)
RP4 = robot finished teatcup attachment
RP5 = robot is in rest position

Fig. 5.- continued. *Simplified schematic representation of the AMS simulation model showing COW, Selection Unit (SU), Milking Unit (MU) and ROBOT processes*

Table 3. *Sensitivity analysis of the random generator with respect to the quality indicators for the AM-CCT method, based on 10 independent model runs*

Quality indicators	*Refer to Fig. 5*	*Units*	*Average values for 10 runs*	*Standard Deviation*	*95% Confidence interval Lower bound*	*95% Confidence interval Upper bound*
Cow waiting presentation to SU - entering SU (average)	A - B	min	2.75	0.14	2.65	2.84
Cow waiting presentation to SU - entering SU (max)	A - B	min	52.40	5.52	48.46	56.35
Cow finished eating conc.-permission to walk to MU or CS (average)	D - G1/D - G2	min	2.54	0.07	2.49	2.59
Cow finished eating conc.-permission to walk to MU or CS (max)	D - G1/D - G2	min	77.61	13.63	67.87	87.35
Cow waiting for attachment (average)	I - L	min	1.99	0.01	1.98	1.99
Cow waiting for attachment (max)	I - L	min	4.72	0.03	4.70	4.75
Cow waiting for milking (average)	B - L	min	7.45	0.05	7.41	7.49
Cow waiting for milking (max)	B - L	min	80.73	13.46	71.11	90.35
Cow occupation time of system (average)	B - CP1	min	8.60	0.23	8.44	8.76
Cow occupation time of system (max)	B - CP1	min	85.79	13.67	76.02	95.56
Average lactating cows	-	number	50.09	0.19	49.96	50.23
Average milking interval for a year	L - L	h	7.93	0.04	7.91	7.96
Average milking interval for April	L - L	h	7.90	0.09	7.83	7.97
Max. milking interval for April	L - L	h	20.37	1.00	19.66	21.08
Min. milking interval for April	L - L	h	2.28	0.13	2.19	2.38
Number of SU visits per cow	-	number	4.82	0.14	4.71	4.92
Number of MU visits per cow	-	number	3.02	0.01	3.01	3.03
Use of SU	B - SP1	% time/day	30.01	0.37	29.74	30.27
Occupation of MU	H - N	% time/day	37.09	0.27	36.90	37.28
Use of MU	E - MP1	% time/day	44.64	0.29	44.43	44.85
Use of milking robot	RB2 - RB1	% time/day	23.63	0.17	23.51	23.75
Average milk yield per milking	-	kg	7.72	0.08	7.66	7.78

***Table 4.** Sensitivity analysis of the random generator with respect to the quality indicators for the AM-HCT method, based on 10 model runs*

Quality indicators	*Refer to Fig. 5*	*Units*	*Average values for 10 runs*	*Standard Deviation*	*95% Confidence interval Lower bound*	*Upper bound*
Cow waiting presentation to SU - entering SU (average)	A - B	min	102.85	0.66	102.37	103.32
Cow waiting presentation to SU - entering SU (max)	A - B	min	261.90	2.20	260.33	263.47
Cow finished eating conc. - permission to walk to MU or CS(average)	D - G1/D - G2	min	8.53	0.03	8.50	8.55
Cow finished eating conc. - permission to walk to MU or CS (max)	D - G1/D - G2	min	12.51	0.33	12.27	12.75
Cow waiting for attachment (average)	I - L	min	1.86	0.01	1.85	1.86
Cow waiting for attachment (max)	I - L	min	4.58	0.26	4.39	4.76
Cow waiting for milking (average)	B - L	min	11.13	0.04	11.10	11.16
Cow waiting for milking (max)	B - L	min	15.74	0.36	15.48	16.00
Cow occupation time of system (average)	B - CP1	min	17.40	0.07	17.35	17.44
Cow occupation time of system (max)	B - CP1	min	22.85	0.35	22.60	23.10
Average lactating cows	-	number	50.09	0.19	49.96	50.23
Average milking interval for a year	L - L	h	11.99	0.00	11.98	11.99
Average milking interval for April	L - L	h	11.99	0.01	11.99	12.00
Max. milking interval for April	L - L	h	14.13	0.09	14.07	14.19
Min. milking interval for April	L - L	h	8.24	0.68	7.75	8.72
Number of SU visits per cow	-	number	2.00	0.00	2.00	2.00
Number of MU visits per cow	-	number	2.00	0.00	2.00	2.00
Use of SU	B - SP1	% time/day	30.12	0.17	30.01	30.24
Occupation of MU	H - N	% time/day	26.98	0.15	26.87	27.08
Use of MU	E - MP1	% time/day	31.23	0.17	31.11	31.35
Use of milking robot	RB2 - RB1	% time/day	15.66	0.06	15.61	15.70
Average milking time window duration for a year	-	h/day	7.55	0.04	7.52	7.58
Average milking time window duration for April	-	h/day	8.97	0.06	8.92	9.01
Average milk yield per milking	-	kg	11.69	0.14	11.59	11.79

5. Testing the model

Although the model can simulate a wide range of (fictitious) AMS arrangements and working conditions, it will be clear that the validation of the model can only be shown for a system that is already applied in practice. The model was tested against a two stall automatic milking system of the type developed by Prolion Development N.V. (Bottema, 1992). The application of the AM-HCT method was followed on a commercial farm. The milking process together with results of the capacities of the milking robot are described in detail in Sonck and Donkers (1995) while a detailed description of the research environment is given in Sonck (1995). To test the model, we derived the milking capacities of the system, expressed in cows per hour, for simulated milking sessions with the same average duration of machine milking as those of the observed milking sessions. Table 5 shows the measured and predicted milking capacities and the absolute and relative differences between both for six different milking sessions on one farm in the morning as well as in the afternoon. The average difference in system capacity amounted to 2.20% and the error in predicting system capacity did not exceed 5%.

Table 5. *Comparison between predicted and measured values of the milking capacity of a two-stall automatic milking system. Absolute and relative differences of the predicted and measured capacities*

	Milking capacity		*Difference*	
Milking no	*Predicted, cows/h*	*Measured, cows/h*	*Absolute cows/h*	*Relative %*
1	13.42	13.41	+0.01	+0.07
2	13.90	14.58	-0.68	-4.66
3	13.79	14.02	-0.23	-1.64
4	14.27	14.42	-0.15	-1.04
5	14.12	13.97	+0.15	+1.07
6	13.99	13.36	+0.63	+4.72

6. Discussion

The validation could only be carried out on the AM-HCT method. However, for the AM-CCT method the robot process elements and cow activities in the milking stalls remain the same, only the use of selection units and the presentation of cows to the system which is based on voluntary visits, are different. As mentioned before, the voluntary presentation of cows to the system is based on experimental data (Devir et al., 1993a). Changing the layout of the cowshed, the AMS arrangements or adjusting decision making parameters related to selection criteria for milking and concentrates supplementation might influence the (diurnal) visiting behaviour pattern of cows to the system (Ketelaar-de Lauwere, 1992; Winter et al., 1992; Devir, 1995). Such influences cannot be a priori incorporated in a model. The user has to keep this in mind. However, it is possible to change the cows' visiting behaviour pattern by adjusting the characteristics of the Beta distributions and to create more frequent visiting behaviour patterns during preset periods of the day. The program language has the facility to test other distributions too. So, new information about the cows' visiting pattern to the system can easily be included in the program, e.g. by using the data analysis method described by van Elderen (1994). In our model, the lactation stage of the cows does not affect the cows' visiting patterns to the system. For that matter, Ipema et al. (1987) with a simulated frequent milking regime reported that the number of milkings per cow per day was fairly constant during a lactation.

The AM-HCT method under standard conditions imitates the processes of a Prolion Development milking robot (Bottema, 1992) and the process times as derived by Sonck and Donkers (1995). However, the model has the ability to change the sequence of certain processes, the process times, the priority for proceeding, the milking priority and other parameters. Therefore, the model is flexible enough to imitate other types of automatic milking systems too, even with another type of milking robot, and to calculate their quality parameters.

Since data are not available to support breakdown models for the estimation of the occurrence of robot failures and their repair times, a *tentative* model is built in the model and can be discussed. However, effects of different degrees of system efficiency, being the proportion of milking robot *downtime* and milking robot *busy time*, on the milking process can be studied. Data on the occurrence of failures as well as repair times, collected on commercial farms are needed.

Ipema et al. (1992) reported a milk yield increase by about 14% with an increase in the milking frequency from 2 to 4 times daily. The production effect tended to be more pronounced in weeks 13 to 25 of lactation in this experiment. In the model, the production level of the herd is not automatically adjusted to the milking frequency, nor do the lactation curves change in function of milking frequency. However, the user can choose the expected production level (i.e. standard cow production) for the aimed milking frequency, which partially solves the above-mentioned shortcoming.

The current model can be extended to incorporate, e.g. :

- the use of experimental data for the individual cow presentation interval, the attachment duration and the milking duration;
- the use of an expert system to select the preferred cow for milking from those available in the SUs and to decide upon the concentrate supplementation in SUs and MUs and even whether a cow in an SU should be milked or has to be diverted to the cowshed (Devir, 1995);
- instead of showing only figures on the PC screen, the working of an AMS could be better visualized by showing the cow movements, the robot process elements and the activities of the farmer and by diagramming the most important quality indicators in function of the time. A prototype of the described animation is under development.

All unexpected events, where human assistance to the AMS is required, are stored in a separate file. This makes it possible to study the effects of a lower reliability of the system (caused by cow-induced disturbances or robot component failures) on the daily labour planning. For that purpose, the current model should be extended with a module for work planning and for calculation of labour requirements for these unexpected and unplanned operations. An accompanying paper deals with this problem (Sonck et al., 1996).

In future the model will be used in a labour budgeting program to determine the labour requirement for different types of AMS farms, in technological assessment studies, e.g. feasibility studies on the use of a milking robot in conventional milking parlours, and in demonstrations to researchers, advisers and dairy farmers. For the latter application, a prototype of an animation program showing the behaviour of the model on a PC is available.

7. Conclusions

To study the *interdependency* of automatic milking system functioning and the farmer's labour planning on operational level, the components of the AMS-farmer relation have been analysed and incorporated in a dynamic stochastic simulation model. So far, the simulation model has shown to be a very powerful technique to test genuine systems or systems still under development. With respect to the great flexibility on the input side, it can be concluded that the AMS simulation model is capable to cope with a large variety of AMS arrangements suitable for modern dairy farms and can, therefore, be used in various ways to support the development of better and new automatic milking systems and to assist the farmer in selecting the most appropriate AMS arrangement and working method for a given farm situation. Until now, only few field tests have been carried out with AMS's. This model could be an aid for preliminary studies of field tests and for assessing the efficiency of the system under different AMS and dairy management strategies and the effects on the daily labour planning and labour requirement for automatic milking.

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Chapter 6

Interdependency of automatic milking and operational labour planning on a dairy farm : comparison of strategies

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Abstract

The integration of the milking robot in the dairy farm will release the farmer from the conventional everyday milking job. Irregularities with the cow traffic in the cowshed as well as with the milking robot itself may occur during automatic milking. An understanding and quantification of the effects of these irregularities on the milking process and on the labour planning at operational level are required.

The purpose of this paper was to describe the modelling approach to study the interdependence of automatic milking and labour planning at operational level and the heuristic procedure of a program for labour planning quality. The modelling approach allows to judge the quality of the automatic milking process which can be influenced by the labour planning of the farmer and the labour planning quality which can be influenced by AMS working.

To illustrate the use of the program, experiments were carried out with a herd of 80 cows and using two automatic milking methods : automatic milking with computer-controlled cow traffic and with human-controlled cow traffic. Experiments for the method with computer-controlled cow traffic deal with control operational decisions related to : (1) bringing cows to the AMS by the farmer; (2) robot failures and repair by the farmer or a maintenance technician; (3) milking of 'problem' cows; (4) combination of automatic milking and pasturing of cows. Experiments for the method with human-controlled cow traffic deal with the influence of different AMS arrangements on the occupation (or required availability) of the farmer to the system.

The results from the experiments indicate that the chosen AMS management strategy strongly determines the absolute and relative importance of the labour requirement for planned and unplanned milking operations. In addition, quality indicators reveal the importance of a permanently available maintenance service to assure the quality of the milking process and of a suitable training of the farmer which gives him the basics to repair small robot failures.

Key words : automatic milking, labour planning, milking robot

Notation

AM-CCT	automatic milking with computer-controlled cow traffic
AM-HCT	automatic milking with human-controlled cow traffic
AMS	automatic milking system
AMS-MS	automatic milking system management strategy
CCTU	unplanned milking operation for the automatic milking method with computer-controlled cow traffic
CS	cowshed
D	distance between workplace and automatic milking system
Del	delay indicator
DW	degree of availability and willingness to execute an operation or a job
HCTU	unplanned milking operation for the automatic milking method with human-controlled cow traffic
In	interruption indicator
MU	milking unit
NMJ	non-milking job
P	person or farm worker
PMO	planned milking operation
PN	preference number referring to the sequence of handling the unplanned milking operations
RA	robot arm
S	travelling speed
SA	social activities and activities with respect to personal care
SP	place of a social activity
SU	selection unit
UD	urgency degree to execute a milking operation
UMO	unplanned milking operation
WP	workplace or work station
$_d$	index referring to duration of an operation or a job
$_{fro}$	index referring to transport from the AMS
$_{g,h,i,j,k}$	counters
$_s$	index referring to start of an operation or a job
$_{to}$	index referring to transport to the AMS

1. Introduction

The success of fully automatic milking will mainly be determined by the degree of autonomous working of the automatic milking system (AMS). The farmer's involvement in the system will depend on his own strategical decisions how to implement the AMS in his dairy and the degree of automation of the management functions of the system, i.e. milking frequency, cow traffic and concentrate allocation (Devir et al., 1995b,c). The main AMS management strategies are : (1) the fully-automatic strategy with computer-controlled cow traffic based on voluntary visits of cows to the milking point during 24 h of the day, a well-considered layout of the cubicle house and a concentrate supplementation and milking at individual cow level; (2) a semi-automatic strategy with farmer-controlled cow traffic based on milkings at fixed moments of the day and with supervision of the farmer and with individual concentrate supplementation through computerized self-feeders or in groups through a total mixed ration (Maltz et al., 1992). The chosen AMS management strategy will determine the time and frequency of the milking operations (Sonck, 1995). The farmer's involvement will however also depend on the reliability of the automatic milking process. A smooth working implies that cows present themselves voluntarily and at the right moments to the system for the fully-automatic strategy. Cows might have difficulties to adapt to a certain routine (Devir et al., 1995a) and if this problem cannot be solved technically in the layout of the cowshed (Ketelaar-De Lauwere, 1992; Livshin et al., 1995), the farmer has to bring certain cows to the system. A smooth working implies also that the system itself works foolproof. However, in practice this might not always be the case.

Although some robots already possess an autocorrection system that is able to detect and correct a number of faults, other faults or other makes of robots still require a human intervention when the robot fails.

In the case of a 'cow traffic' problem or a 'robot technical' problem the assistance of the farmer or a service technician is required to ensure the continuation of the milking process. The fact that Dutch and Belgian family dairy farms employ little or no external staff and since other non-milking jobs or activities need also to be performed makes that the farmer or a collaborator is not always immediately available to solve a problem. Therefore, a considerable time lag can arise between the actual alert, the arrival of the farmer or a collaborator and solving of the problem. A prolonged interruption of the cow traffic or the milking robot will adversely affect the milking process. In addition, interruptions of non-milking jobs or activities, to operate the AMS, will negatively affect the daily labour planning. It is clear that the allocation of time of the farmer to jobs in a robotic milking dairy farm will be very important to meet the quality of the milking process (e.g. the aimed milking frequency) and the quality of work (e.g. interruptions of non-milking jobs). Understanding and quantification of the mutual influence of AMS performance and the farmer's labour planning at operational and tactical level are required.

This paper describes the modelling approach to study the interdependency of automatic milking and labour planning at operational level and the heuristic procedure for labour planning quality. The program is descriptive and indicates how labour planning and labour requirement can be influenced by the farmer's choices to manage the AMS and by the functioning of the system. In the second part of the paper the effects of the implementation of different AMS management strategies subjected to different operational decisions on labour planning and labour requirement are presented using the program for labour planning quality. Attention is also paid to the quality indicators of the milking process and the applicability of the AMS management strategies on dairy farms.

2. Materials and methods

2.1. General

The allocation of labour time to workers under uncertain circumstances (e.g. unexpected machine breakdown) is not specific to the robotic milking dairy farm, but to many continuously operating services where decisions must be made in an ever-changing environment. Doukidos and Paul (1990) present industrial examples on work planning and simulation. Siferd (1992) gives a review on hospital nursing models for workforce staffing and scheduling. Linear programming, goal programming, multi-criteria decision making, dynamic programming, simulation and scheduling are used as mathematical tools. In a review on operational decision making models in farm planning and management, van Elderen and Kroeze (1994) concluded that the expected development for farm operational planning will be simulation within the context of a database with historical, current and expected data and with decision support systems aimed at optimal solutions obtained from linear or dynamic programming, heuristic algorithms, expert systems or a combination of these approaches.

In our study a dynamic stochastic simulation of the AMS extended with *a module for labour planning quality* based on a heuristic procedure containing simple priority rules for operations scheduling is used. Fig. 1 shows a schematic overview of the modelling approach. A description of this simulation model is given by Sonck and van Elderen (1996). The *module* offers the possibility to define a daily work schedule of the farmer's jobs and activities. The (un)availability of the farmer to the AMS in the daily schedule has to correspond with this in the simulation model. For evaluation of the farmer's planning quality, the module uses the following data : the daily work schedule, unplanned milking events of the simulation model and planned milking operations calculated with the calculation module of Sonck (1995). When unplanned milking events occur, the module for labour planning quality formulates an altered schedule and calculates the supplementary labour requirement while it indicates the interrupted or delayed jobs and activities. The following section describes the organisation of the daily work schedule of the farmer's jobs and activities and the applied priority rules for labour planning.

2.2. Concept of the module for labour planning quality

Job definitions and characteristics

To establish a baseline of the jobs and activities of the farmer and other farm workers a task definition and time allocation survey are needed. In the module we distinguish the following classes of jobs or activities on the robotic milking dairy farm : (1) the milking job; (2) non-milking jobs (e.g.

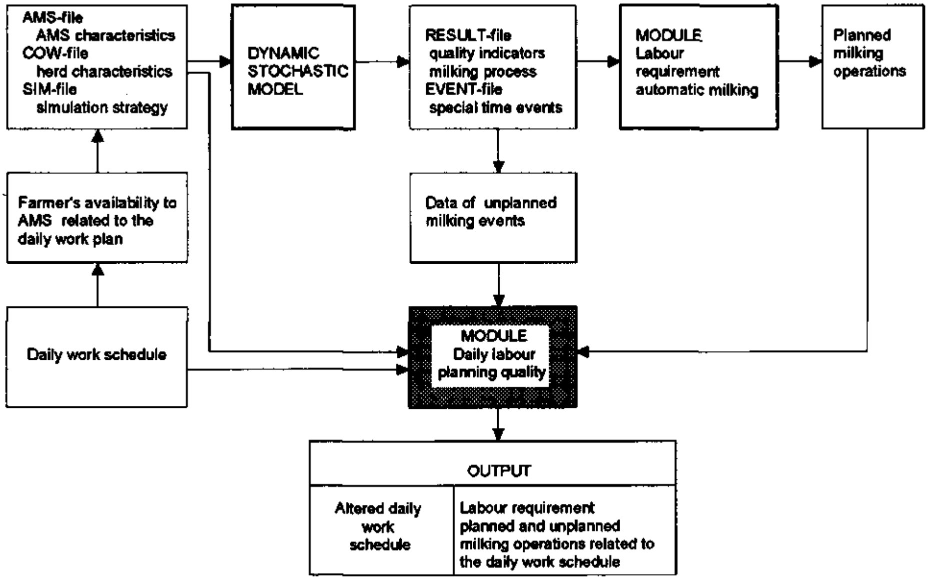


Fig. 1. *Schematic overview of the modelling approach*

feeding the young stock); (3) personal care (e.g. sleeping) and social activities (e.g. family trip). All have to be defined and scheduled.

Fig. 2 gives a view on the jobs and activities and their respective characteristics that are explained further. The *milking job* consists of unplanned and planned milking operations. The milking operations depend on the applied AMS strategy. We distinguish automatic milking with computer-controlled cow traffic (AM-CCT) and automatic milking with human-controlled cow traffic (AM-HCT). The labour requirement for the *unplanned* milking operations (UMO) are derived from the 'event' file of the simulation model (Sonck and van Elderen, 1996) and from the transport time to and fro the AMS which is determined by the labour planning of the daily jobs of the farm workers. Three types of *unplanned* milking operations for the AM-CCT method ($CCTU_i$) and for the AM-HCT method ($HCTU_i$) are defined. These are :

- repair of robot failures by the farmer or a technician : moment of occurrence as well as labour requirements derived from the event file of the simulation model ($CCTU_1$ and $HCTU_1$);
- problems with cows which do not visit the milking unit in time (low visiting frequency). Cows exceeding a preset maximum milking interval for the AM-CCT are supposed to be brought to the milking stall by a person ($CCTU_2$ and $HCTU_2$);
- problems with the attachment of teatcups to cows ($CCTU_3$ and $HCTU_3$); (1) the farmer can intervene immediately for each case or (2) only when the milking interval of a particular cow exceeds the maximum allowable milking interval or (3) the cow can be separated in a separation area after an unsuccessful teatcup attachment and treated during fixed periods of the day .

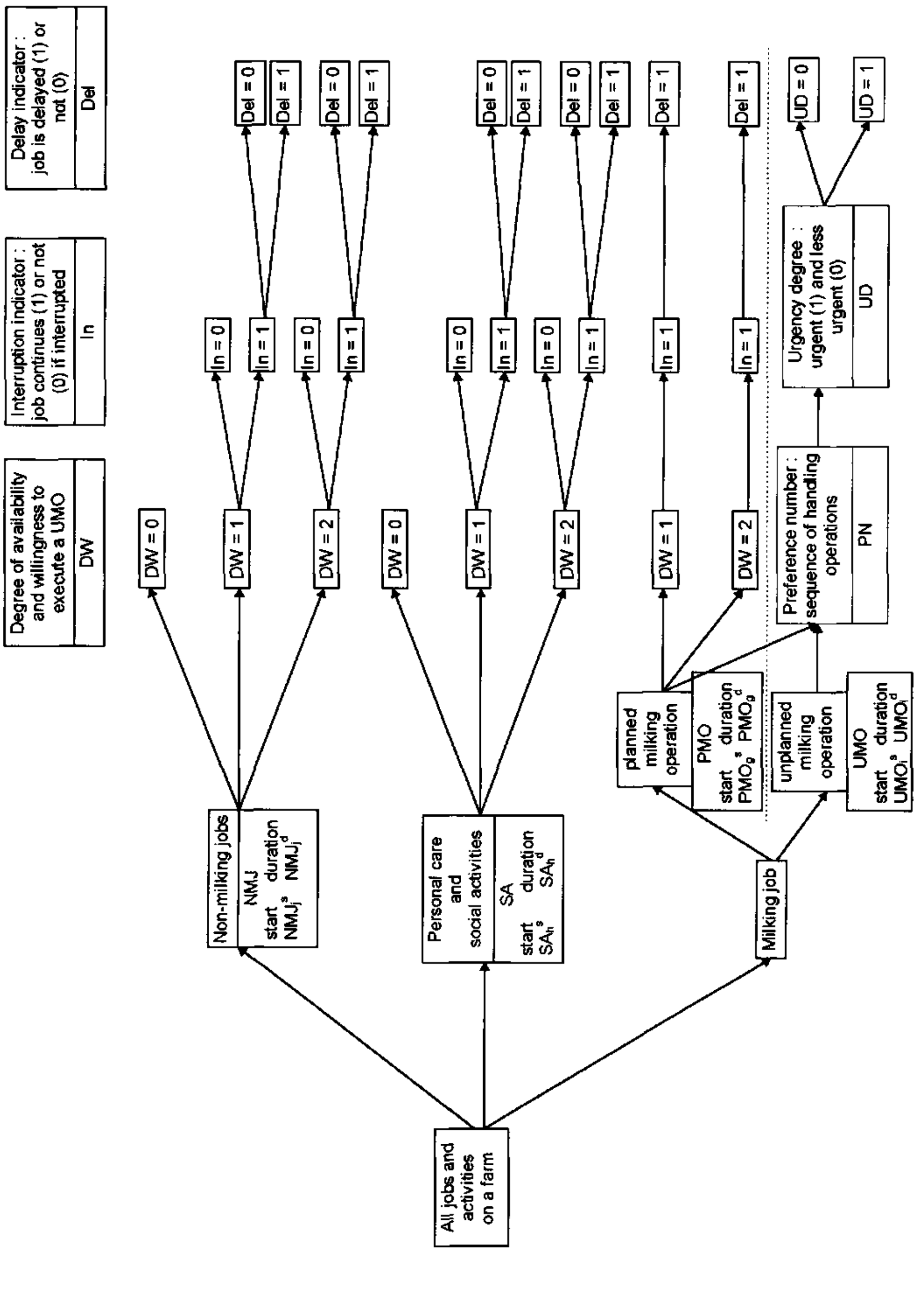


***Fig. 2.** View on the classes of jobs and job characteristics on a robotic milking dairy farm, as defined in the program for labour planning quality on automatic milking*

The sequence of handling UMOs if two or more UMOs occur at the same time is managed by building in a hierarchy; the UMOs with a high preference number, symbol $PN[CCTU_i]$ or $PN[HCTU_i]$ will be executed first. Furthermore, an urgency degree (UD) is attached to each UMO :

- 'urgent' means that the operation is really important for the further functioning of the AMS : urgent UMOs are assigned with $UD[CCTU_i] = 1$;
- 'less urgent' means that the operation can be delayed : less urgent UMOs are assigned with $UD[CCTU_i] = 0$.

The allocation of the two urgency degrees to the UMOs is defined as follows :

$UD[CCTU_i] = 1$ for each $CCTU_i$ with $PN[CCTU_i] \geq f$

$UD[CCTU_i] = 0$ for each $CCTU_i$ with $PN[CCTU_i] < f$

with f the limit preference number (Remark : ditto formulae for HCTU operations).

Sonck (1995) described the *planned* milking operations of the milking job (PMO) and its labour requirement for both AM methods with different grazing systems. The planned milking operations for the AM-CCT method contain : (1) the sum of the work elements related to rinsing of the milking installation and cleaning of the milking area; (2) the starting-up procedure of the AMS after a cleaning period. These groups of operations have to be executed at fixed moments of the day to obtain cleaning intervals of less than 12 hours in order to maintain a good microbial milk quality (Verhey, 1992); (3) Supervision and control which can be planned whenever the farmer wants. The planned milking operations for the AM-HCT method contain : (1) the make ready work elements of all milkings of a day; (2) the put away work elements of all milkings of a day; (3) supervision and control including displacements of the farmer, driving of cows to the entrance of the AMS area and checking cow characteristics on the terminal; (4) if 'short grazing periods' are applied supplementary work is required to drive cows from the pasture to the cubicle house.

Each of these planned milking operations is assigned to the farmer and farm workers and to certain periods of the day :

$P_k[PMO_g^s, PMO_g^d]$ = person k is occupied with the planned milking operation $\mathbf{PMO_g}$ that starts at moment $\mathbf{PMO_g^s}$ of the day and has a duration of $\mathbf{PMO_g^d}$ hours.

Preference numbers and urgency degrees are attached to PMO in the same way as to UMO. The PMOs can be handled in two ways : (1) PMOs are handled only if no urgent or less urgent UMO occur; otherwise the UMOs are handled first; (2) PMOs are handled only if no urgent UMO; otherwise the urgent UMO is handled first.

In the module, the non-milking jobs, personal care and social activities are not divided in successive operations. The allowances for troubleshooting, interruptions or rest for the worker are supposed to be included in the duration of the non-milking job or activity. The scheduling of these jobs or activities and their expected durations are defined for each working person on the farm who might be involved in an unplanned milking operation and stated as follows for the non-milking jobs :

$P_k[NMJ_j^s, NMJ_j^d]$ = person **k** is occupied with non-milking job $\mathbf{NMJ_j}$ that starts at moment $\mathbf{NMJ_j^s}$ of the day and has a duration of $\mathbf{NMJ_j^d}$ hours.

We use a similar logic in defining the scheduling of personal care and social activities (for example eating, reading newspaper, sleeping, etc.) :

P_k [SA_h^s , SA_h^d] = person **k** is occupied with social activity $\mathbf{SA_h}$ that starts at moment $\mathbf{SA_h^s}$ of the day and has a duration of $\mathbf{SA_h^d}$ hours.

To each non-milking job, personal care and social activity, a degree of availability and willingness (DW) to execute unplanned milking operations, is attached :

DW = 0 : the person is not available or within reach, or is not willing to execute less urgent or urgent UMOs, e.g. he cannot be disturbed in the job or activity.

DW = 1 : the person is available but is only willing to execute urgent UMOs.

DW = 2 : the person is available and is willing to execute urgent and less urgent UMOs.

Each non-milking job, personal care or social activity is further typified by an *interruption indicator* (**In**) and a *delay indicator* (**Del**). The interruption indicator specifies whether a job or activity does continue after it has been interrupted by an unplanned milking operation (**In = 1**) or does not (**In = 0**). The delay indicator points out, if **In = 1**, whether the job or activity will be delayed (**Del = 1**) or not (**Del = 0**).

As a machine-breakdown or troubleshooting might occur during the execution of jobs and activities, the workplace WP_j of each job NMJ_j or the place SP_h of personal care or social activity SA_h needs to be characterized to determine the transport time of the person called to intervene in the automatic milking process :

WP_j [D_j , S_j^{to} , S_j^{fro}] = the workplace of a non-milking job $\mathbf{NMJ_j}$ and is characterized by the distance $\mathbf{D_j}$ between the workplace and the AMS, the travelling speed of the person to ($\mathbf{S_j^{to}}$) and fro ($\mathbf{S_j^{fro}}$) the AMS.

The same characteristics SP_h [D_h , S_h^{to} , S_h^{fro}] are defined for the place of a social activity. The periods of the day that are not defined in the work schedule of a person are considered as 'free time' and can always be interrupted by UMOs.

Solution method

The program shows how the planning of the farmer can be affected by an AMS. All persons on the farm are assigned a rank number to handle UMOs. The person with the lowest rank number will be checked first on his availability and willingness to handle a UMO. Persons with a rank number of 0 are not allowed to intervene. A SEARCH procedure starts for jobs or activities that coincide with a UMO for the person with rank number = 1 :

$$\left[UMO_i^s, UMO_i^s + UMO_i^d\right] \cap \left[PMO_g^s, PMO_g^s + PMO_g^d\right] \neq \varnothing$$

$$\left[UMO_i^s, UMO_i^s + UMO_i^d\right] \cap \left[NMJ_j^s, NMJ_j^s + NMJ_j^d\right] \neq \varnothing$$

$$\left[UMO_i^s, UMO_i^s + UMO_i^d\right] \cap \left[SA_h^s, SA_h^s + SA_h^d\right] \neq \varnothing$$

If jobs or activities coincide with a UMO, priority rules determine whether the job (activity) will be executed first or the UMO. Fig. 3 shows the priority rules applied in different steps of the SEARCH and SOLUTION procedure.

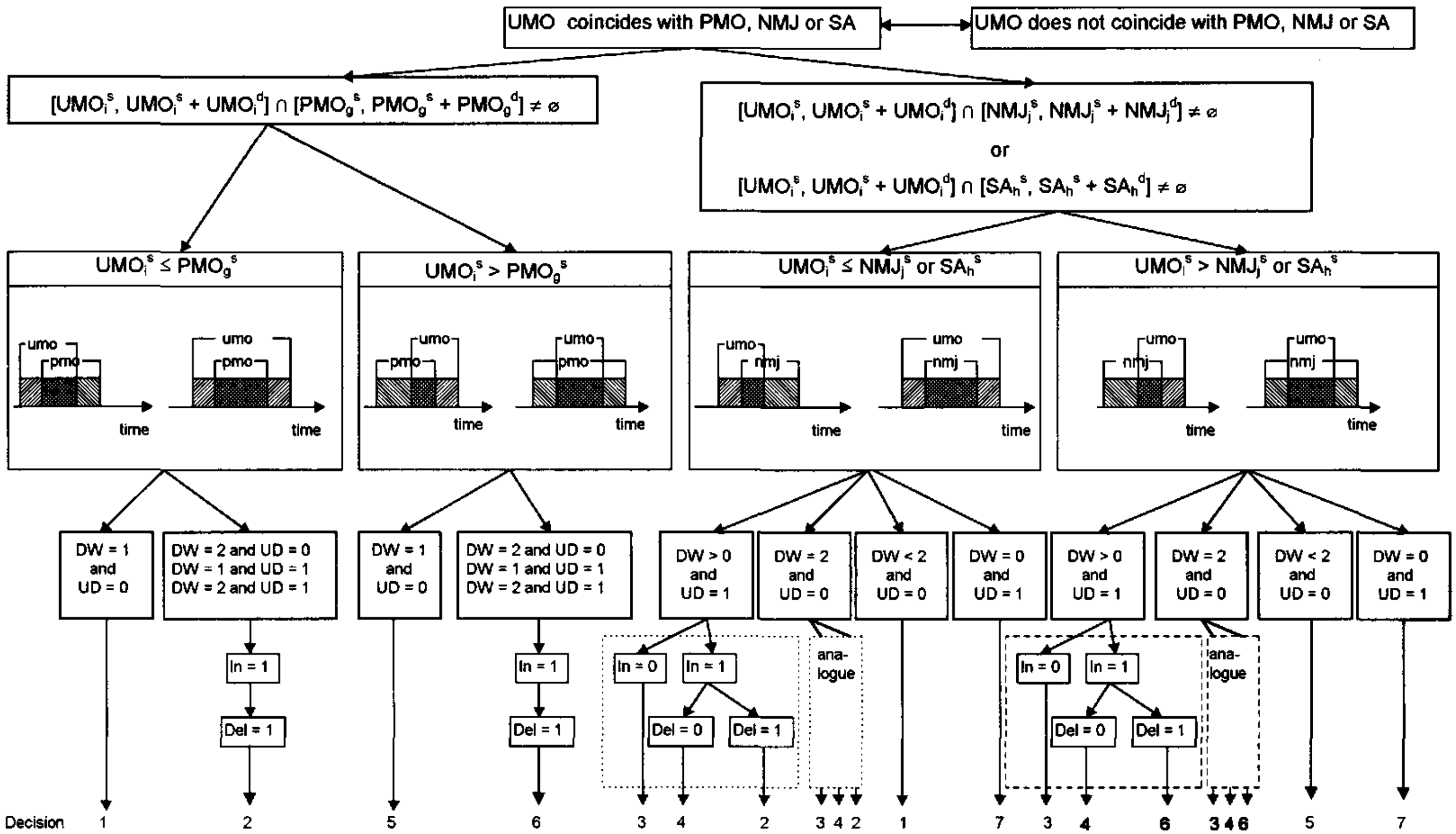
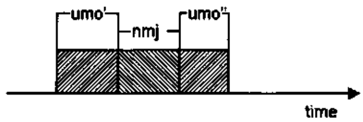
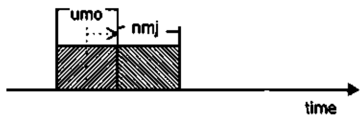
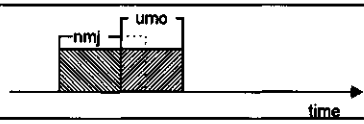
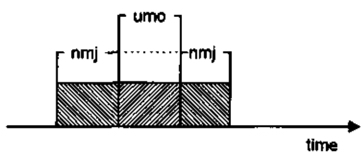
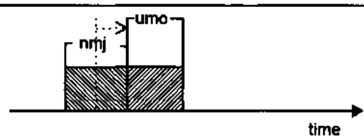
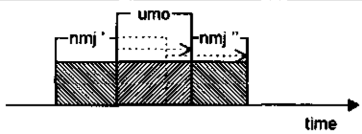


Fig. 3. *Priority rules in the different steps of the SEARCH and SOLUTION procedure of the program for labour planning quality with automatic milking*

In the last step of the SOLUTION procedure, the priority rules result in a decision how to handle the jobs or activities. These decisions are explained in Table 1, illustrated with a figure for each decision.

Table 1. *Explanation and illustration of the decisions made to handle the unplanned milking operations which coincide with other jobs and activities*

Decision number	*Decision*	*Figures*
1	The UMO is started, but split into two work intervals, one before and one after the job or activity. The UMO is interrupted to execute the planned job or activity.	
2	The UMO is started and completed. A job or activity that had to be started during the UMO is delayed and starts when the UMO is completed	
3	The job or activity is stopped before its completion to execute immediately a UMO that occurs.	
4	The job or activity is executed during the planned time interval but is interrupted for the completion of a UMO. The UMO is immediately executed when it occurs.	
5	The job or activity is executed as planned, but the UMO that occurs during the job or activity is delayed and starts when the job or activity is completed.	
6	The job or activity starts at the planned time, but is interrupted by the execution of a UMO and is therefore completed later than planned.	
7	The investigated worker is not available to execute a UMO. A worker with a higher rank number is tested on his availability and willingness to do the UMO. The SEARCH and SOLUTION procedure recommences.	

interval. Fig. 4 shows the labour requirement for bringing cows to the AMS for a herd with 50% high and 50% low frequent visiting cows (see Sonck and van Elderen, 1996) and different values of the maximum milking interval : 18 , 16, 14, 12 and 10 h. The cows are brought to the AMS when the time since the last milking equals the maximum milking interval. Fig. 4 clearly illustrates that the labour requirement amounts to 30 min/day or less for a maximum milking interval of 18, 16 and 14 h. On the contrary, if the maximum milking interval is 10 h and 12 h, the labour requirement rises to respectively 79 and 161 min/day on a yearly basis. Fig. 5, in comparison to Fig. 4, allows the conclusion that if the cows are brought to the AMS during three fixed periods of the day (at 7 h 30, 14 h 30 and 21 h 30), the labour requirement drops remarkably. For a maximum milking interval of 10 and 12 h, this 'group' treatment results in a labour saving of 50% in comparison with an 'individual' treatment of cows. It is clear that this reduction is obtained by the lower transport time of the worker. However, where each individual cow is brought to the AMS and milked within the maximum milking interval, group treatment of cows results in a milking interval higher than the maximum milking interval for a certain number of cows. The average milking interval is 20.57, 19.26, 16.12, 14.92 and 13.17 h for cows that exceed the maximum milking interval of respectively 18, 16, 14, 12 and 10 h and that are brought in group to the AMS.

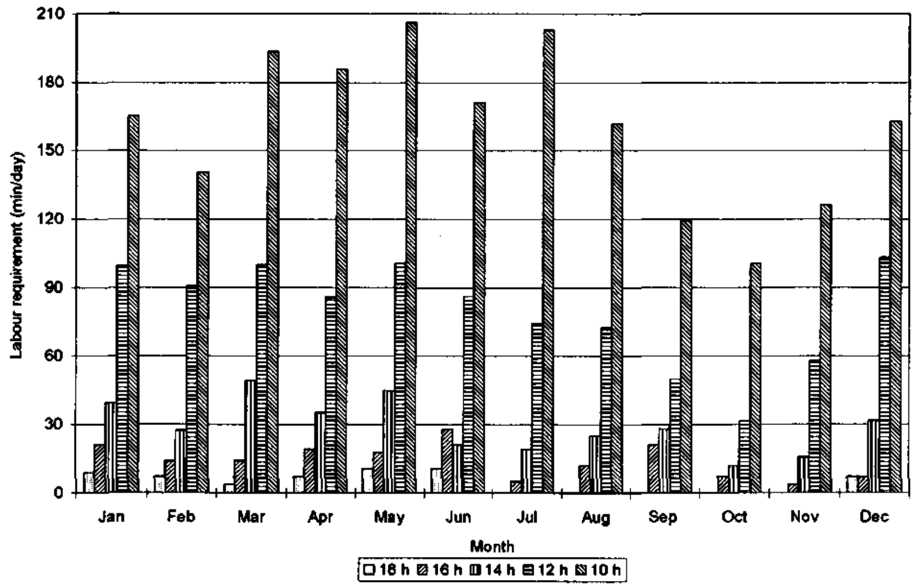


Fig. 4. Labour requirement (min/day) for bringing cows to the AMS, which exceed a maximum presentation interval of 10, 12, 14, 16 and 18 h. The cows are brought to the AMS when the time since the last milking equals the maximum presentation interval. Method = AM-CCT; Herd size = 80; House type = 2 + 2 row cubicle house with 2 SU and 2 MU

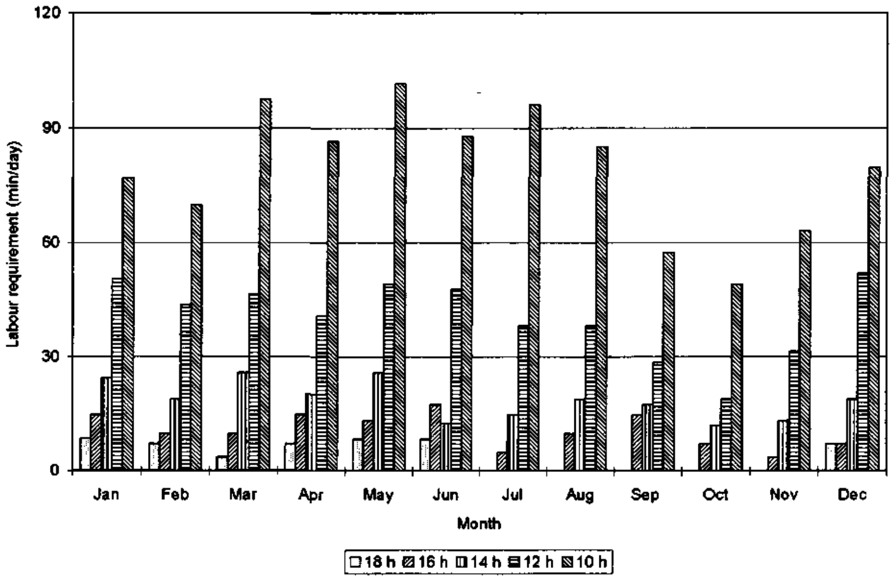
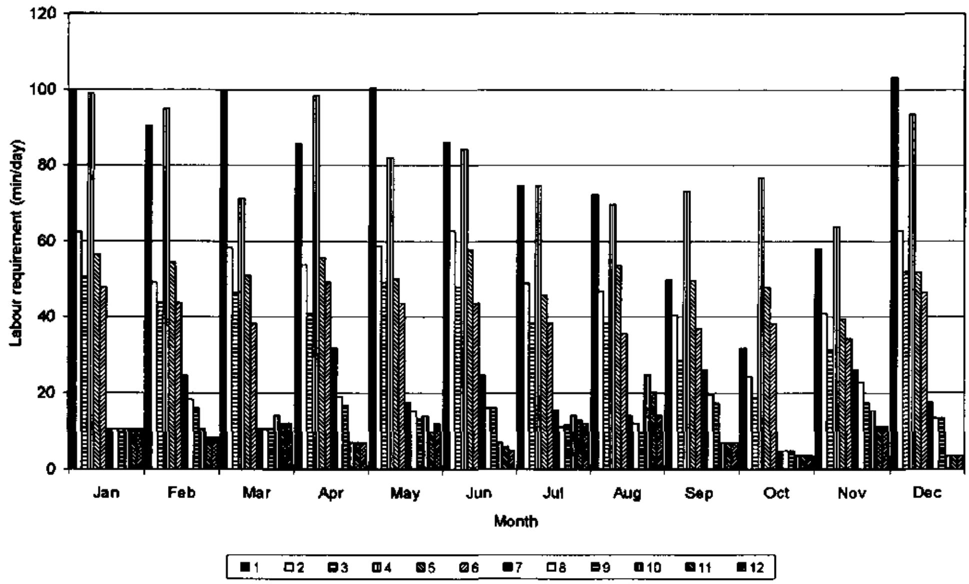


Fig. 5. Labour requirement (min/day) for bringing cows to the AMS, which exceed a maximum presentation interval of 10, 12, 14, 16 and 18 h. The cows are brought to the AMS during three periods of the day, namely at 7 h 30, 14 h 30 and 21 h 30. Method = AM-CCT; Herd size = 80; House type = 2 + 2 row cubicle house with 2 SU and 2 MU

Fig. 6 allows to assess the influence of the AMS visiting pattern of cows and the farmer's choices in the treatment of cows on the labour requirement for bringing cows to the AMS. Four AMS visiting patterns of the herd and three different treatments of cows are considered in the simulation. The work schedule shown in Table 2 is used in the program. A treatment with a UD = 1 indicates that the cows are immediately brought to the AMS as soon as they exceed the maximum milking interval (here, 12 h). A UD = 0 refers to the fact that the cows are brought to the AMS whenever the labour planning allows it, i.e. according to the priority rules included in the program.

Fig. 6 shows that the labour requirement is much lower if the herd consists of only high frequent visiting cows. In comparison with case 1, a herd with 100% high frequent visitors results in a 76 to 89% lower labour input for bringing cows to the AMS. The differences in labour requirement between cases with and without a day-night cow visiting pattern are negligible. It affects in combination with the treatment of the cows, labour distribution (required for bringing cows) during the day.

For example, Table 3 shows a comparison between the proportional distribution of the labour requirement (in %) for the three fixed periods for case 3, 6, 9 and 12, stated in Fig. 6. The high percentage for the group 7 h 30 in all the cases can be explained by the higher time interval (from 21 h to 7 h 30 = 10 h) : the probability that a cow exceeds its maximum milking interval is higher. In herds with a day-night visiting pattern (case 6 and 12), relatively more labour is required at 7 h 30 and 21 h 30 than at 14 h 30, in comparison with herds without a day-night pattern (case 3 and 9) : the difference amounts to 3 - 7%.



Cases

Herd characteristics	*Treatment of cows*		
	UD = 1*	*UD = 0*	*in fixed periods***
50% high-50% low frequent visitors	*case 1*	*case 2*	*case 3*
50% high-50% low frequent visitors with day-night pattern	*case 4*	*case 5*	*case 6*
100% high frequent visitors	*case 7*	*case 8*	*case 9*
100% high frequent visitors with day-night pattern	*case 10*	*case 11*	*case 12*

**UD = urgency degree for bringing cows to the system*

*** Cows exceeding their maximum milking interval are brought to the system during three fixed periods of the day, starting at 7 h 30, 14 h 30 and 21 h 30.*

Fig. 6. *Labour requirement (min/day) for bringing cows to the AMS, which exceed a maximum milking interval of 12 h, in twelve cases. Method = AM-CCT; Herd size = 80; House type = 2 + 2 row cubicle house with 2 SU and 2 MU*

Table 3. *Proportional distribution of the labour requirement (in %) over three fixed periods of the day for bringing cows to the AMS. Method = AM-CCT; Herd = 80 cows; House type = 2 + 2 cow cubicle house with 2 SU and 2 MU*

groups	*CASES**			
	3	*6*	*9*	*12*
group of 7 h 30	41.68	44.49	36.39	35.11
group of 14 h 30	28.81	20.23	31.60	25.86
group of 21 h 30	29.45	35.86	32.00	39.03

* The cases are explained in Fig. 6

Table 4 shows the consequences of control operational decisions and differences in herd characteristics on the labour planning for one day (1 May). Due to the unplanned milking operations (bringing cows to the AMS) the original work schedule of Table 2 alters. The influence of the UMOs on the schedule is indicated by work for UMOs executed during planned jobs and by the delay and shortening of planned jobs. The individual treatment (cases 1, 4, 7, 10) agrees with the aimed milking quality (milking interval = 12 h), but it causes a remarkable change in the labour planning of the farmer. The high labour requirement for UMOs results in substantial shortenings of NMJ and SA. In addition, jobs are frequently and longer interrupted by work for UMOs. However, job delay is reasonable. On the contrary, the treatment of cows in fixed periods of the day results in less job delays, no work for UMOs done during planned jobs and a lower labour requirement. The original work schedule changes slightly. The average milking interval of the cows brought to the AMS is 15.23 h, 14.91 h, 14.77 and 15. 08 h for respectively case 3, 6, 9, 12. This is approx. 3 h higher than the aimed maximum milking interval. Besides these two extreme treatments we calculated the treatment with UD = 0. This treatment results in a more regular staggering of the UMOs over the day. For example in case 2 and case 5 cows are brought in small groups to the AMS with a frequency of 5 to 6 times a day. This results also in a remarkable reduction in labour requirement and a lower milking interval (13.41 h in case 2 and 13.60 h in case 5) in comparison with the individual treatment. As UMOs are often executed between two planned jobs, this treatment results in long delays compared to the individual and group treatments mentioned before.

Table 4. *Effect of the unplanned milking operation 'bringing cows to the AMS' on the planned work schedule of a day. Method = AM-CCT; Herd = 80 cows; House type = 2 + 2 row cubicle house with 2 SU and 2 MU*

TIMES (min/day)	CASES *											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
work during PMO	2.76	1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
delay of PMO	4.89	42.71	0.00	0.00	59.08	0.00	0.00	3.51	0.00	0.00	3.51	0.00
shortening PMO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
work during NMJ	45.12	0.00	0.00	22.45	0.00	0.00	3.51	0.00	0.00	10.54	0.00	0.00
delay of NMJ	7.02	5.51	7.24	0.00	2.00	2.93	0.00	0.00	0.00	3.51	0.00	0.00
shortening NMJ	52.14	5.51	7.24	22.45	2.00	2.93	3.51	0.00	0.00	10.54	0.00	0.00
work during SA	47.53	3.51	0.00	44.90	0.00	0.00	3.51	0.00	0.00	3.51	0.00	0.00
delay of SA	11.55	69.05	4.31	11.92	48.59	2.93	0.00	11.43	0.00	0.00	16.05	0.00
shortening SA	40.51	28.13	0.00	56.07	20.22	0.00	3.51	4.41	0.00	3.51	6.27	0.00
shortening free time	9.78	24.79	41.93	3.51	27.87	41.02	8.41	11.02	13.29	0.00	3.51	11.91
sum delays	23.46	117.27	11.55	11.92	109.67	5.86	0.00	14.94	0.00	3.51	19.56	0.00
labour requirement (min/day)	102.53	58.43	49.17	82.09	50.12	43.65	15.43	15.43	13.29	14.06	9.79	11.91
milking interval(h)	12	13.41	15.23	12	13.60	14.91	12	13.94	14.77	12	13.84	15.08

* The cases are explained in Fig. 6

According to Devir and Maltz (1995), a delay in milking has no long-lasting effect on production. Cows seem to be tolerant to short-term (up to 24 hours) delays when subjected to the irregular milking intervals that are typical of robot milking based on voluntary visits (Devir and Maltz, 1995). This suggests that the 'group' treatments ('UD = 0' and 'in fixed periods') which are preferable from labour organisational point of view have a negligible negative effect on the milk production.

When fitting UMOs in his daily work schedule the farmer will have to search for the correct balance between labour quality and the quality of the milking process. The farmer will have to learn how the cows behave in the cubicle house and in function of their visiting pattern (and the cows production level) he has to choose the maximum allowable milking interval. The choice of the maximum milking interval has a marked influence on the number of cows that need to be brought to the AMS and consequently on the labour requirement of this operation.

Control operational decisions related to robot failures and repair

Contrary to conventional milking, fully automatic milking might call at any moment of the day for the farmer's assistance or for the maintenance service of the milking robot company when robot failures occur. Due to labour planning and unavailability of the farmer or transport time of the maintenance service to the farm, the call may not always be answered immediately and a prolonged inactivity of the robot may negatively affect the quality of the milking process. Table 5 shows the milking quality indicators of the milking process for 6 cases. If the farmer is 24 h a day available to respond to robot failures (case 2), the milking interval, the number of SU and MU visits and 'cow waiting times' only change slightly in comparison with reference case 1 without robot failures. If the farmer is only available during certain periods of the day (case 3), the cow waiting time between 'presentation to SU' and 'entering SU' rises from 6 to 50.60 min. The cow waiting time between 'finishing eating concentrates' and 'permission to walk to MU or CS (Cowshed)' and the cow waiting time for milking increase with respectively 51.00 and 35.65%. As the robot is unusable for 2.11 h (case 3), due to robot failures, delay of repair and repair time itself, the number of visits to SU and MU and the MU use are respectively 6.80, 2.65 and 5.12% lower than in case 1. An increased use of the SU is due to the simulation procedure, i.e. cows are blocked in the SU when the system fails. A restricted availability of the farmer in combination with robot failures results in a 2.52% higher average milking interval and in months with a high number of lactating cows even in 11.24%.

Cases 4, 5 and 6 allow to assess the importance of the availability of the maintenance service (see Table 5). We assumed that the maintenance service requires 1 h to reach the farm and on an average 1 h to repair a robot failure. With exception of the first two 'cow waiting times', the deviation of the milking quality indicators of case 4 in comparison with case 1, is not greater than approx. 10%. If the failure free expectation time decreases to 6 h (case 5), the 'cow waiting times', the SU use and the robot idle time increase, the milking interval increases slightly, the MU use decreases while the number of SU and MU visits decreases only slightly. If the maintenance service is only available between 6 h and 22 h, the cow waiting time between 'presentation to SU' and 'entering SU' as well as the other 'cow waiting times' increase remarkably. The 7.38% lower use of the MUs explains the high robot idle time which delays the milking of cows and consequently results in a higher average milking interval for a year (+4.91%) and for the month of May (+10.23%).

The results indicate that a permanently available maintenance service is meaningful to the robotic milking farm, especially on those farms where the AMS already works at the limit of its capacity. In addition, if a farmer is continuously available, and is able to solve the majority of problems himself, failures do not have a large impact on the milking quality indicators. It is remarkable that the milking quality indicators are better in the case that the farmer is only available during four short periods (in total 12.5 h per 24 h of availability) than in the case that the maintenance service is available from 6 h to 22 h (in total 16 h per 24 h availability) and starts to repair the failure with a delay of 1h.

Table 5. *Quality indicators of the milking process for different operational decisions connected with robot failures and repair. Method = AM-CCT; Herd size = 80 cows; 50% high and 50% low frequent visitors; 2 milking units (MU); 2 selection units (SU); cowshed (CS) is a 2+2 row cubicle house*

Indicator of the milking quality	*case 1*	*case 2*	*case 3*	*case 4*	*case 5*	*case 6*
Cow waiting presentation to SU and entering SU (min)	6.00	7.36 (+22.64%)	50.60 (+743.33%)	10.84 (+80.67%)	24.29 (+304.83%)	102.53 (+1608.83%)
Cow finished eating conc.-permission to walk to MU or CS (min)	3.00	3.30 (+10.00%)	4.53 (+51.00%)	3.43 (+14.33%)	4.1 (+36.67%)	5.89 (+96.33%)
Cow waiting for milking (min)	8.33	8.80 (+5.64%)	11.3 (+35.65%)	9.09 (+9.12%)	10.73 (+28.81%)	14.05 (+68.67%)
Cow occupation time of the AMS (min)	9.11	9.47 (+3.95%)	11.57 (+27.00%)	9.64 (+5.82%)	10.77 (+18.22%)	13.96 (+53.24%)
Average milking interval for a year (h)	7.94	7.94 (0%)	8.14 (+2.52%)	7.97 (+0.38%)	8.01 (+0.88%)	8.33 (+4.91%)
Average milking interval for May (h)	7.92	7.93 (+0.13%)	8.81 (+11.24%)	7.95 (+0.38%)	8.15 (+2.90%)	8.73 (+10.23%)
Number of SU visits (number/day and cow)	4.85	4.8 (-1.03%)	4.52 (-6.80%)	4.78 (-1.44%)	4.72 (-2.68%)	4.27 (-11.96%)
Number of MU visits (number/day and cow)	3.02	3.01 (-0.33%)	2.94 (-2.65%)	3.00 (-0.66%)	2.98 (-1.32%)	2.88 (-4.64%)
Use of SU (h/day)	11.26	11.74 (+4.26%)	13.85 (+23.02%)	11.98 (+6.37%)	13.64 (+21.12%)	16.14 (+43.35%)
Use of MU (h/day)	14.25	13.80 (-3.17%)	13.52 (-5.12%)	13.74 (-3.55%)	13.64 (-4.23%)	13.20 (-7.38%)
Repair of failures (h/day)	0.00	0.72	0.72	0.24	0.61	0.56
Robot unusable (h/day)	0.00	0.72	2.11	0.77	1.88	3.79

Explanation cases :

Case 1 : Reference case : no robot failures occur

Case 2 : Robot failures occur and the failure free expectation is 6 h.
The farmer is 24 h available to repair robot failures himself (UD = 1 and DW = 1 for all jobs).

Case 3 : Robot failures occur and the failure free expectation is 6 h.
The farmer is only available to repair robot failures during certain periods of the day : 6h30 - 7h30; 8h00 - 12h00; 13 h00 - 18h00 and 19h30 - 22h00. (UD = 1 and DW = 1 only during the mentioned periods).

Case 4 : Robot failures occur and the failure free expectation is 12 h.
The maintenance service of the milking robot company is required to repair the robot failures. The maintenance service is 24 h available and needs 1 h to reach the farm.

Case 5 : identical to case 4 but with a failure free expectation of 6 h

Case 6 : Robot failures occur and the failure free expectation is 6 h.
The maintenance service of the milking robot company is required to repair the robot failures. The maintenance service is only available between 6 h and 22 h and needs 1 h to reach the farm.

Control operational decisions related to milking of separated cows

Cows which fail automatic teatcup attachment require the assistance of the farmer. The farmer can respond immediately when a problem occurs or, alternatively, the system can separate the cows in a holding area after a maximum number of attachment attempts of the robot. In the latter case the farmer handles a group of separated cows at times apppropriate with his labour planning. This involves driving the cows from the holding area to the MU and supervising the milking process (e.g. the attachment). The labour requirement for this operation is called *assistance time* as it only requires the presence of the farmer but does not require physical labour for 100% of the time. Sonck (1995) reported that only 12 to 20% of the assistance time is spent to physical labour. The assistance time and its effect on the automatic milking process can be calculated with the simulation model (Sonck and van Elderen, 1996) and the program for labour planning. Table 6 shows the milking quality indicators, the number of separated cows and the assistance time for two treatments : (1) cows handled immediately and (2) cows handled in groups. The additional time to use the MUs for the separated cows does not affect the milking interval of all the cows if they are handled separately. In this case, the waiting time for SU and for milking and the milking interval of the separated cows increase only slightly when the percentage of unsuitable cows increases. The milking interval differs maximum 0.55 h from the average milking interval of all cows. The assistance time increases sharply and lasts unacceptably long for percentages above 10%. If cows are treated in groups at three fixed periods of the day, the 'cow waiting times' and the milking interval of all cows rise slightly with increasing percentage of unsuitable cows. The milking interval of the separated cows differs 2.50 h and 4.22 h for respectively 2.5% and 20% unsuitable cows. In comparison with the previous treatment, group treatment results in a remarkable reduction in assistance time. Even for 20% unsuitable cows, the assistance time is only 1.09 h per group. If the farmer aims to spend maximum 0.5 h per group, only 6 to 7% of the herd may consist of unsuitable cows. Culling of cows unsuitable for automatic teatcup attachment can be considered to reduce the labour impact for milking of separated cows. However, if the cow is a high producing one, the decision may be hard. It is up to the farmer to set out the pros and cons before taking a decision.

Table 6. *Milking process quality indicators (mean, on year basis), number of separated cows per day and time required to assist separated cows for two treatments : (1) cows are handled immediately and separately and (2) cows are assisted and milked in group during three fixed periods of the day : 7 h 30, 14 h 30 and 21 h 30*

Treatment	*Data type*	*Percentage of cows unsuitable for automatic attachment*				
		2.50%	*5%*	*10%*	*15%*	*20%*
Separately	Separated cows per day	5	9.87	18.68	29.45	39.13
	Assistance time (h/day)	1.23	2.46	4.56	7.37	9.80
	Cow waiting for SU (min)	6.02	6.05	6.64	8.27	9.74
	Cow waiting for milking (min)	8.02	8.08	8.21	8.49	8.69
	Milking interval of all cows (h)	7.94	7.94	7.95	7.97	7.95
	Milking interval of separated cows (h)	7.39	8.12	7.41	8.21	8.21
In group	Separated cows per day	3.43	6.33	14	19.98	26.27
	Assistance time (h/day)	0.89	1.25	2.10	2.70	3.28
	Cow waiting for SU (min)	6.31	7.54	9.42	12.28	15.09
	Cow waiting for milking (min)	8.07	8.00	8.19	8.19	8.35
	Milking interval of all cows (h)	7.92	7.96	8.00	7.98	7.98
	Milking interval of separated cows (h)	10.68	10.86	11.51	12.02	12.20

Combination of automatic milking and pasturing of cows

Sonck (1995) described the milking operations and the associated labour requirement for work methods where automatic milking and pasturing of cows are combined. The main concern, when cows are on the pasture for a period, is to know to what extent the milking process will be affected. Literature reports no experiments where pasturing and automatic milking are combined. Therefore, we simulate the worst case, i.e. none of the cows visit the AMS during pasturing. Table 7 shows milking quality indicators for fully automatic milking with and without 5 h of pasturing and for two different visiting behaviour patterns of the herd. The herd with 50% high and 50% low frequent visitors is able to absorb the 5 h of pasturing. The number of SU and MU visits and the MU use hardly differ from the situation without pasturing and the average milking interval increases only

0.47h. Longer cow waiting times for milking explain the higher SU use. The herd consisting of 100% high frequent visitors is not able to make up for 'lost time' of pasturing and to reach the same frequency of visits to the SU and MU. SU and MU visits decrease remarkably. SU use with pasturing hardly differs from SU use without pasturing. During the first 7 months of the year the two SUs are not able to serve the herd with the 100% high frequent visitors and the SUs reach their maximum capacity of 80% in use (19h of 24h in the cowshed). This explains the SU use of 69.36% as mean on a yearly basis. The limited capacity of the SUs forms a bottleneck and limits the use of the MUs. The MUs never reach their maximum use of 80%.

Table 7. *Milking quality indicators for automatic milking with or without 5 h pasturing of the cows and for herds with different visiting behaviour pattern. Method = AM-CCT; Herd size = 80 cows. AMS with 2 SU and 2 MU*

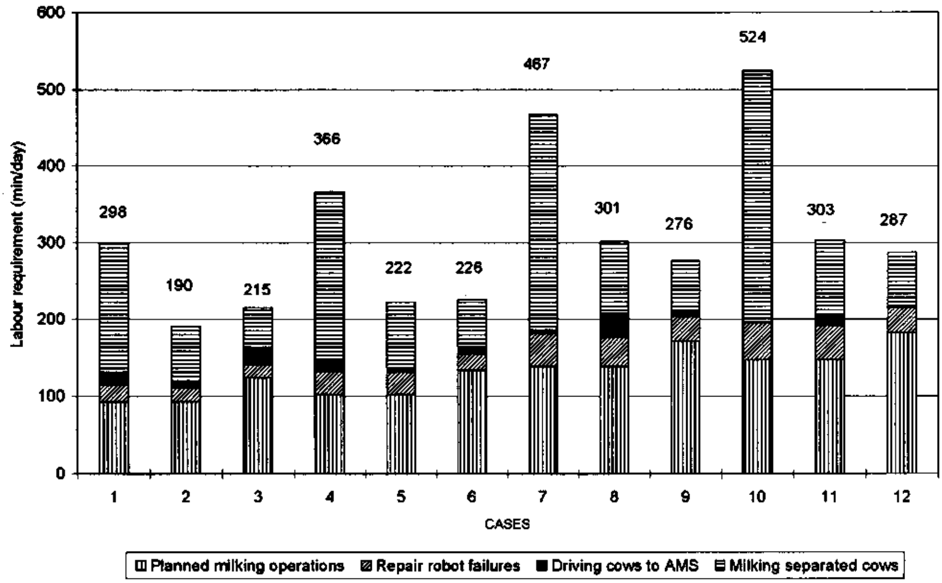
Data type	*5 h pasturing (8 h - 13 h)*			
	*without**	*with**	*without***	*with***
SU visits per cow and per day	4.90	4.73	7.72	4.96
MU visits per cow and per day	3.04	2.98	3.97	3.40
Cow waiting for milking	8.26	9.76	8.78	10.63
Milking interval (h)	7.86	8.33	6.04	7.06
SU used (% per 24h)	46.71	55.11	70.94	69.35
MU used (% per 24 h)	59.36	56.40	73.14	63.57

* Herd with 50% low and 50% high frequent visitors and with a maximum milking interval set at 14 h.
**Herd with 100% high frequent visitors and with a maximum milking interval set at 12 h.

In the cases with pasturing, we assumed that the AMS visiting frequency of the cows increased during their stay in the cowshed. Therefore, the activity was artificially (in the program) raised with 26% (i.e., 5 h/19 h) and set at zero during the pasturing period. No research is available on AMS visiting behaviour of cows during or after a pasturing period. A very low visiting pattern during the pasturing period and a high visiting pattern just after the pasturing period or during the whole (shortened) stay in the cowshed, might be possible. An overcrowded AMS might discourage cows to visit the AMS and as a consequence results in more work for the farmer to drive cows to the system. The program is able to simulate these variants.

Total labour requirement for different AMS management strategies and different herd sizes

Whereas the previous results deal separately with the effects of each type of unplanned milking operations on the labour planning and the milking process, the cases defined in Fig. 7 consider the occurrence of all unplanned milking operations. Three different AMS management strategies (AMS-MS) are simulated : (1) the farmer is always available to repair failures and to assist 'AMS unsuitable cows' immediately; no pasturing period is included; (2) a limited availability of the farmer to repair failures and to assist 'AMS unsuitable cows' which are handled during three periods; (3) identical to AMS-MS 2 but with only two periods to handle 'AMS unsuitable cows' and with a pasturing period of 5 h. These three AMS-MS's are applied on herds of 60, 80, 100 and 120 cows.



For each case : Robot failures might occur and the failure free expectation is set at 12 h.
Each herd consists of 100% high frequent visitors.
Each herd has 5% of cows which are unsuitable for automatic teatcup attachment.
The maximum milking interval is 12 h.
For cases 1 to 6 : 2 row cubicle house.
For cases 7 to 12 : 2 + 2 row cubicle house.

CASE	*Herd size*	*MUs*	*SUs*	*Farmer's availability for repair of robot failures*	*Farmer's availability for milking separated cows*	*Pasturing period for the cows*
1	*60*	*2*	*2*	*0 - 24 h*	*0 - 24 h*	*None*
2	*60*	*2*	*2*	*6 - 22 h*	*08h00-08h30/14h30-15h00/21h30-22h00*	*None*
3	*60*	*2*	*2*	*6 - 22 h*	*08h00-08h30/14h30-15h00*	*08h30-13h30*
4	*80*	*2*	*2*	*0 - 24 h*	*0 - 24 h*	*None*
5	*80*	*2*	*2*	*6 - 22 h*	*08h00-08h30/14h30-15h00/21h30-22h00*	*None*
6	*80*	*2*	*2*	*6 - 22 h*	*08h00-08h30/14h30-15h00*	*08h30-13h30*
7	*100*	*3*	*3*	*0 - 24 h*	*0 - 24 h*	*None*
8	*100*	*3*	*3*	*6 - 22 h*	*08h00-08h30/14h30-15h00/21h30-22h00*	*None*
9	*100*	*3*	*3*	*6 - 22 h*	*08h00-08h30/14h30-15h00*	*08h30-13h30*
10	*120*	*3*	*3*	*0 - 24 h*	*0 - 24 h*	*None*
11	*120*	*3*	*3*	*6 - 22 h*	*08h00-08h30/14h30-15h00/21h30-22h00*	*None*
12	*120*	*3*	*3*	*6 - 22 h*	*08h00-08h30/14h30-15h00*	*08h30-13h30*

Fig. 7. Labour requirement (min/day) for planned and unplanned milking operations under different AMS management strategies for the AM-CCT method

The AMS-MS 1 results in unacceptable high total labour requirements (sum of PMO and UMO) for all herd sizes (case 1, 4, 7, 10) under the considered circumstances. The UMOs are responsible for approx. 70% of the total labour requirement for the milking job (Fig. 8). The comparison of the AMS-MS 2 and AMS-MS 3, allows to conclude that the total labour requirement is 13% and 1.8% higher for herd sizes of respectively 60 and 80 cows. This can be explained by the higher labour input for bringing cows from the pasture to the cowshed for cases 3 and 6. The lower increase for 80 cows is due to the fact that with pasturing the AMS visiting frequency during the period that the cows are in the cowshed is higher. As a consequence, the SUs cannot serve all cows in time and this limits the use of the MUs. This means that 'AMS unsuitable cows' are unable to visit the MU as frequent with pasturing as without pasturing which results in a lower labour requirement for assisting unsuitable cows. The same can be mentioned for the AMS-MS 2 and 3 for herd sizes of 100 and 120 cows. Here, the lower labour requirement for assisting unsuitable cows compensates the higher labour requirement for the planned milking operations and explains the lower total labour requirement for the AMS-AM 3 in comparison to AMS-AM 2. Fig. 8 shows the relative importance of the milking operations. The planned milking operations take approx. 30%, 47% and 60% respectively for AMS-MS 1,2 and 3.

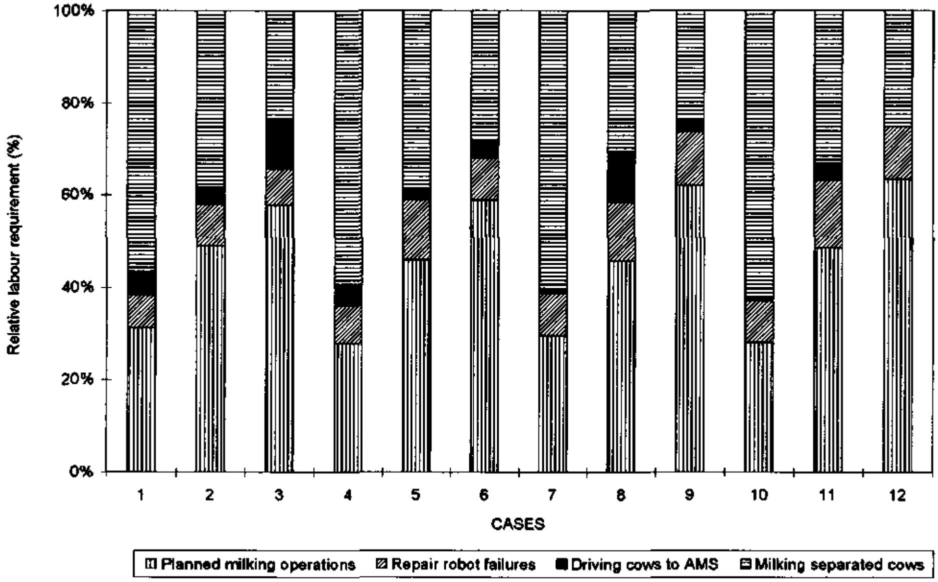


Fig. 8. Proportion of planned and unplanned milking operations of the milking job for different AMS management strategies (see Fig. 7 for explanation of the cases)

3.2. Labour planning for automatic milking with human-controlled cow traffic

As cows are milked during planned periods of the day, automatic milking with human-controlled cow traffic excludes the element of uncertainty outside the milking periods. During the milking periods however, the farmer has to be in the neighbourhood of the AMS to intervene when the system fails, technical problems occur or when the cow traffic is held up. The farmer is functioning as supervisor while he is executing non-milking jobs in the cowshed (e.g. feeding young cattle). Sonck (1995) described the farmer's involvement at the start, at the end and during an AM-HCT milking and concluded that *labour savings of up to 37.9%* are possible in comparison with conventional milking. As the milking capacity of a milking robot with one or two stalls is low (Sonck and Donkers, 1995), the milking of 50 cows lasts more than five hours with the AM-HCT method (Sonck, 1995) and ties the farmer too long . The simulation program and program for labour planning offer a tool to investigate alternative AMS arrangements to reduce the milking periods and as a consequence the time that the farmer is bound to the milking parlour. This is of great importance for the farmer's daily planning of his jobs. In addition, the programs enable to assess the waiting times for cows and the milking interval. Fig. 9 shows the milking time (h/day) for different AMS arrangements, for three milkings per day and for a herd of 80 cows. Approx. 15% of the milking time (= assistance time) is spent to physical labour (Sonck, 1995). The arrangement with two rows of milking units and 1 robot arm (RA) supposes a rotary robot arm, otherwise one robot arm can only serve one row of milking units. If the farmer presumes to be available for interventions during maximum three times two hours, he needs at least 2 x 3 milking units with two robot arms for attachment. For an arrangement with four MUs, the mean milking time, on a yearly basis lasts three times 3 h. This arrangement still offers the opportunity for a herd of 80 cows to combine automatic milking with pasturing (e.g. a short period of 5 h).

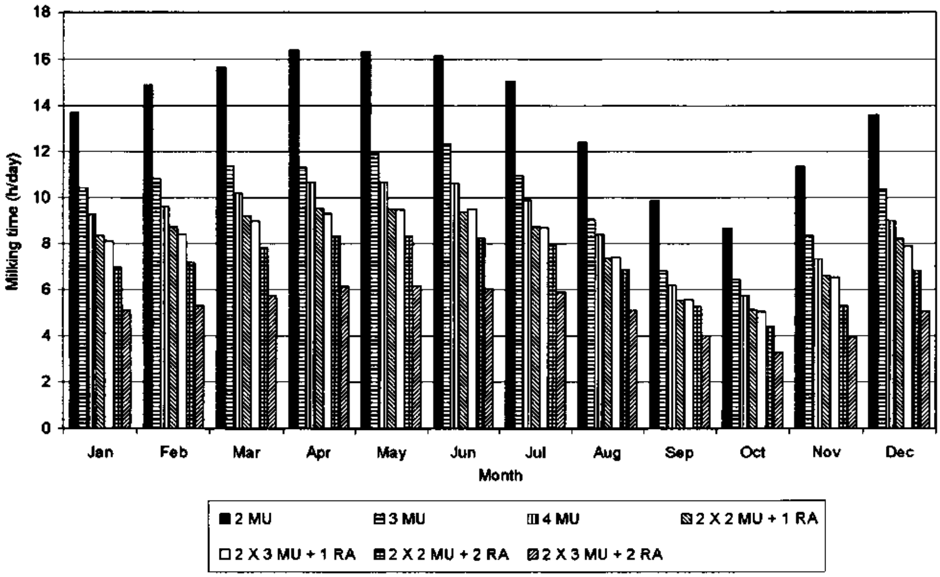


Fig. 9. Milking time (h/day) for automatic milking with human-controlled cow traffic and for different AMS arrangements. Herd size = 80 cows; Milking frequency = 3 times/day; MU = milking unit; RA = robot arm

Fig. 10 clearly illustrates that the mean and maximum cow waiting times for SU reduce sharply when the number of MUs increases from 2 to 4 MUs and when the system is extended with an additional robot arm. The maximum milking interval shows the same trend and amounts to 10.53 h and 8.83 h for respectively a 2 MU and 2x3 MU+2 RA arrangement. In the latter case the maximum milking interval is only 0.83 h higher than the aimed milking interval of 8 h.

The results of the AM-HCT method show that if this method is to be included in the labour planning of the farmer the capacity of the system needs to be increased. Results of this simulation agree with those reported by Sonck and Donkers (1995) who discussed the possibilities to increase the capacity of a milking robot by means of a formula of tuning. Results clearly show the effect of an

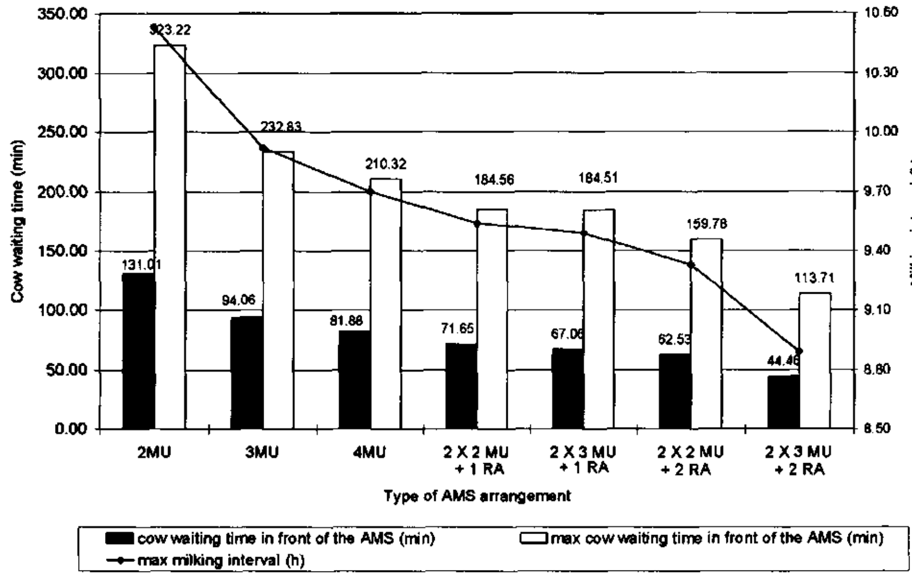


Fig. 10. *The mean cow waiting time between presentation to SU and entering SU ('cow waiting for SU'), the mean and maximum cow waiting time between entering SU and the start of milking ('cow waiting for milking') and the maximum milking interval for different AMS arrangements. MU= milking unit; RA = robot arm*

increased number of milking units and robot arms (if it concerns a double-sided arrangement) on the milking capacity. In the context of the AM-HCT method, the feasibility of installing a milking robot in conventional milking parlours needs to be investigated. It may open new perspectives for the application of the milking robot, especially on large farms with more than 80 cows. The number of milking units and robot arms could then be chosen in function of herd size and the presumed assistance time. On large-scale farms one or two persons are normally responsible for supervision over automatic milking and for continuous maintenance of the systems.

4. Conclusions

The simulation and program for labour planning quality offer a tool to study the consequences of automatic milking on labour planning at operational level. The fact that elements of uncertainty can be included makes it possible to assess the effects of a milking robot working at reduced capacity or of a herd with a low visiting pattern to the AMS on labour requirement and labour planning quality.

The experimental results allow us to reach the following conclusions :

(1) Individual treatment with 'bringing cows to the AMS' that exceed their maximum milking interval results in an unacceptable high labour requirement, especially when the herd consists of a high percentage of less frequent AMS visiting cows. On the contrary, group treatment with 'bringing cows to the AMS' results in a lower labour input, but delays the milking of these cows with

approx. 3 h. However, it is still acceptable for a chosen maximum milking interval of 10 h and 12 h, especially when it concerns a minority of the herd.

(2) The day-night visiting pattern has no effect on the amount of labour for 'bringing cows to the AMS'. However, it affects the spreading of the labour for this milking operation. In our experiments we found a 3 to 7% higher labour requirement during the morning and evening periods than during the afternoon period when cows are brought to the AMS during three fixed periods of the day.

(3) The 'group' treatments ('UD = 0' and 'in fixed periods') are preferable with respect to the low labour requirement, the low impact on labour planning and the negligible negative effect on the average milking interval and the milk production.

(4) A permanently available maintenance service is very important to assure the quality of the milking process, especially on those farms where the AMS already operates at the limit of its capacity. The results suggest that a training of the farmer which gives him the basics to repair small robot failures is a worthwhile investment.

(5) The program enables to derive conditions for the performance of the milking robot related to the automatic attachment. In our experiments, we found that if the farmer aims to spend a maximum of 0.5 h per group (three groups per day) for milking separated cows, the herd may consist of 6 to 7% of cows unsuitable for automatic attachment. The assistance time (= milking time of the separated cows) consists mainly of supervision. Only 12 to 20% of the time is used for physical work (Sonck, 1995).

(6) The possibility for combining automatic milking with pasturing of cows will depend largely on the behaviour of the cows during the shortened stay in the cowshed. In the experiments we assumed that the cows compensate the lost hours of pasturing with a relatively higher AMS visiting frequency in the cowshed. If the herd consists of low and high visiting cows, the system was able to serve the cows. For a herd with only high visiting cows, the system was overcrowded during their stay in the cowshed. If automatic milking is combined with pasturing, it is well worth to foresee some extra capacity for the system.

(7) The AMS management strategy will determine the absolute and relative importance of the labour requirement for planned and unplanned milking operations. With regard to the amount of labour for the different AMS-MS's under unfavourable circumstances, it is obvious that unplanned milking operations lead to marked reductions in labour savings with the AMS. Therefore, high demands are set to AMS functioning and cow traffic to the AMS.

(8) The AM-HCT method can only be applied on farms with a small herd size (< 50 cows) when only two milking stalls are available. Application of the AM-HCT method on large farms, requires an extension of the AMS with milking stalls and eventually with a robot arm. Therefore, the installation of a milking robot in conventional milking parlours might be an economically attractive solution for this capacity problem.

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Chapter 7

A study of the labour organisation at tactical level on robotic milking dairy farms

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Abstract

One of the last steps towards a completely automated dairy farm or robotic milking dairy farms is full automatic milking by means of an automatic milking system. The introduction of automatic milking will have consequences on the dairy farms as well as on the overall dairy industry. This paper focuses on evaluating labour organisational consequences at tactical level of using an automatic milking system on Dutch model dairy farms. By combining two programs, namely the IMAG-ARBGRO labour budgeting program, extended with task time modules for automatic milking and the program 'Standards for Fodder Supply', it was possible to calculate the labour budget of robotic milking dairy farms with various grazing patterns and to compare these farms with conventional milking dairy farms. Therefore, a number of farming plans (FPs) of robotic and conventional milking dairy farms were defined.

From the results, it was clear that, if summerfeeding is applied, labour savings of 6.6 and 9.3% are possible respectively for robotic milking dairy farms with only grassland (45 ha) and for others with grassland (35 ha) and land for forage maize crops (10 ha) compared to conventional milking dairy farms with unrestricted grazing. Disregarding additional forage surplus work, stated in these robotic milking dairy farms, the labour savings amount respectively to 15.7 and 20.0%, both with summerfeeding. Comparing various grazing systems for FPs with only grassland and with the same milk quota, we found that zerograzing results in the greatest labour reduction (17.6%) and summerfeeding in the smallest reduction (6.6%). Ignoring the additional work of forage surplus, all grazing systems combined with automatic milking result in a labour reduction of at least 15% with a maximum of 22.2% for an unrestricted grazing system with supplementary feeding of 6 kg DM maize silage. Comparing various grazing systems for FPs with grassland and maizeland and with unchanged milk quota, zerograzing once again results in the greatest labour reduction (18.8%) and summerfeeding in the smallest reduction (9.3%). However, disregarding the work for forage surplus, summerfeeding appears to be the best alternative with 20% or 816 h labour reduction. If the milk quota are extended in order to keep the same herd size, we found the same as above, as far as the differences between the grazing systems are concerned. However, the labour reduction amounts only to 1.8 to 13.8% for FPs with grassland and to 9.5 to 21.3% for FPs grassland and maizeland. Farmers using contract workers for grass silage production will profit the most of automatic milking in terms of labour reduction. For these farms, the labour reduction amounts to 20.0 (923 h) to 29.6% (1371 h) for farming plans with only grassland and with contract work and to 17.9 (816 h) to 29.9% (1361 h) for farming plans with grassland and maizeland and with contract work. On these farms, automatic milking combined with summerfeeding appears to be the best alternative.

Key words : automatic milking, labour budgeting, grazing systems, labour

Notation

AM	automatic milking
AMS	automatic milking system
CCT or AM-CCT	automatic milking with a computer-controlled cow traffic
CM	conventional milking
CMDF	conventional milking dairy farm
CW	contract work
DM	dry matter
FP	farming plan
FPCM	fat protein corrected milk
FP grass	farming plan with 45 ha of grassland
FP maize	farming plan with 35 ha of grassland and 10 ha of forage maize crops
HCT or AM-HCT	automatic milking with a human-controlled cow traffic
HMP	herringbone milking parlour
RMDF	robotic milking dairy farm
R4 + 3 or 6	restricted grazing or overnight housing with supplementary feeding of 3 or 6 kg DM maize silage per day
Sf	summerfeeding or day and night housing of cows with feeding of roughage (grass or maize silage)
SFS	standards for fodder supply
U4	unrestricted grazing or day and night grazing with every 4 days a new plot
U4 + 3	unrestricted grazing with supplementary feeding of 3 kg DM maize silage per day
U6	unrestricted grazing or day and night grazing with every 6 days a new plot
U10	unrestricted grazing or day and night grazing with every 10 days a new plot
Zg	zerograzing or day and night housing of cows with feeding of fresh cut grass

1. Introduction

Full automatic milking is one of the last steps towards a completely automated dairy farm where milking is no longer a job as on conventional milking dairy farms (CMDF) where it occupies the milker approx. 3 hours every day (Sonck et al., 1991; Keller, 1994). Dairy cows are then milked with an automatic milking system (AMS) and without human intervention. An AMS comprises a milking robot with one or more milking stalls. The cowshed is equipped with facilities that control the cow traffic towards the milking point. An expert system controls and makes decisions related to cow individual milking frequency and concentrate and even roughage supplementation (Devir, 1995; Ipema and Rossing, 1987). A system for automatic detection and registration of illness and oestrus (Schlünsen et al., 1987; Maatje et al., 1992) is also part of an AMS. A management system presents the information in a convenient arrangement to the farmer and spurs him on to take decisions and to come into action. It is clear that an AMS offers tools to monitor, to control and to manage a dairy herd. Farm management on robotic milking dairy farms (RMDF) will be characterized by the possibilities to detect abnormalities and to decide more quickly and accurately than on conventional milking dairy farms.

Most of the consequences of automatic milking on the dairy farms as well as on the overall dairy industry are still unclear (de Boer et al., 1994). As for each new technology, the knowledge of the economic consequences of adopting an AMS will be a major concern of the farm manager to employ it (Harsh et al., 1992). It is also of particular concern to potential AMS users to know how automatic milking on their individual dairy farm will influence labour planning and organisation and social (family) life. To investigate problems with labour demand or supply, labour planning systems have been used for many years, e.g. in Germany, Kreher (1950) developed the first systematic approach of farm labour budgeting for a whole year; in the Netherlands Kroeze (1975) proposed the basic approach to compare labour demand and supply for field work and later on Jäger (1979) did the same in Germany; Chen (1986) and Gekle (1981) developed work planning systems to budget several alternative machinery complements. More recently, Nielsen and Sørensen (1993) developed a calculation program for work requirement, work capacity, work budget and work profile. None of the mentioned work planning systems include calculations for robotic milking dairy farms. To estimate the impact of an AMS on the labour for the farmer, work planning systems need to be updated.

2. Objectives of the study

The paper will focus on evaluating labour organisational consequences of using an AMS on Dutch model dairy farms, approached at tactical level (yearly basis). Four objectives have been formulated for the study. The first and primary objective is to quantify the labour requirement for robotic milking dairy farms. This means that the milking and non-milking jobs have to be considered. Thereby we want to compare the labour amount on robotic milking dairy farms where the farmland is fully used for grassland with those where the farmland is partly used for forage maize crops. The second objective is to find out to what extent different grazing systems that can be combined with automatic milking influence the labour requirement for grass silage production, grassland care and the care for dairy cows and young stock. The third objective is to study the effects of decisions related to the milk quota on the labour requirement. As more frequent milking with the AMS will raise the milk production with approx. 15% (Ipema et al., 1987), the farm manager can reach his milk quota with a smaller number of dairy cows or he can decide to buy additional milk quota and to keep the same number of cows. Finally as fourth objective, the effects of automatic milking on labour requirement and labour saving for farms where contract workers are employed for the production of grass silage are investigated.

To evaluate these objectives, a study has been performed on the basis of simulation models. To allow calculations related to the objectives, a number of farming plans are formulated. A farming plan is defined here as the aggregate of starting-points that are characteristic of a certain dairy farm (Mandersloot, 1992). The aim of this paper is first to describe the calculation method to determine the labour requirement and labour supply, and secondly to define the farming plans of the model dairy farms. Then, the results of labour budgeting of the model farms are presented and discussed according to the above-mentioned objectives. Finally, the paper closes by drawing conclusions with respect to the objectives of the study.

3. Materials and methods

3.1. Calculation method

The calculation method, schematically shown in Fig. 1, is based on a combination of two programs : 'Standards of Fodder Supply' (SFS) of the Research and Advisory Station for Cattle, Sheep and Horse Husbandry in Lelystad (Anonymous, 1991; Mandersloot et al., 1991) and the IMAG-ARBGRO farm budgeting program (Kroeze, 1982; Kroeze, 1993). Since in this research we are interested in the influence of different grazing systems combined with automatic milking on the total labour requirement, the SFS program is used for calculation of pasture utilization and distribution schemes of labour such as for mowing, pasture harrowing and fertilizing. This program comprises three parts : (1) *The fodder requirement,* being the required energy of grass, roughage or concentrates for the herd, is computed by means of three simulation models : the cow model (Hijink and Meijer, 1987), the young stock model (Mandersloot, 1989) and the dairy herd model (Mandersloot and van der Meulen, 1991). (2) *The fodder supply* consists of grass and roughage (grass and maize silage) of the farmland and of purchased concentrates and roughage, if necessary. The grass supply, as grass production per parcel and per cut, is computed from the grass growth model. (3) *The tuning* between fodder requirement and supply is done with the pasture utilization model. Based on results obtained with the grass growth model, the grass intake of the herd can be computed together with pasture utilization. Once the pasture utilization is simulated, the amount of roughage that can be harvested on proper farmland and the amount that needs to be bought are known.

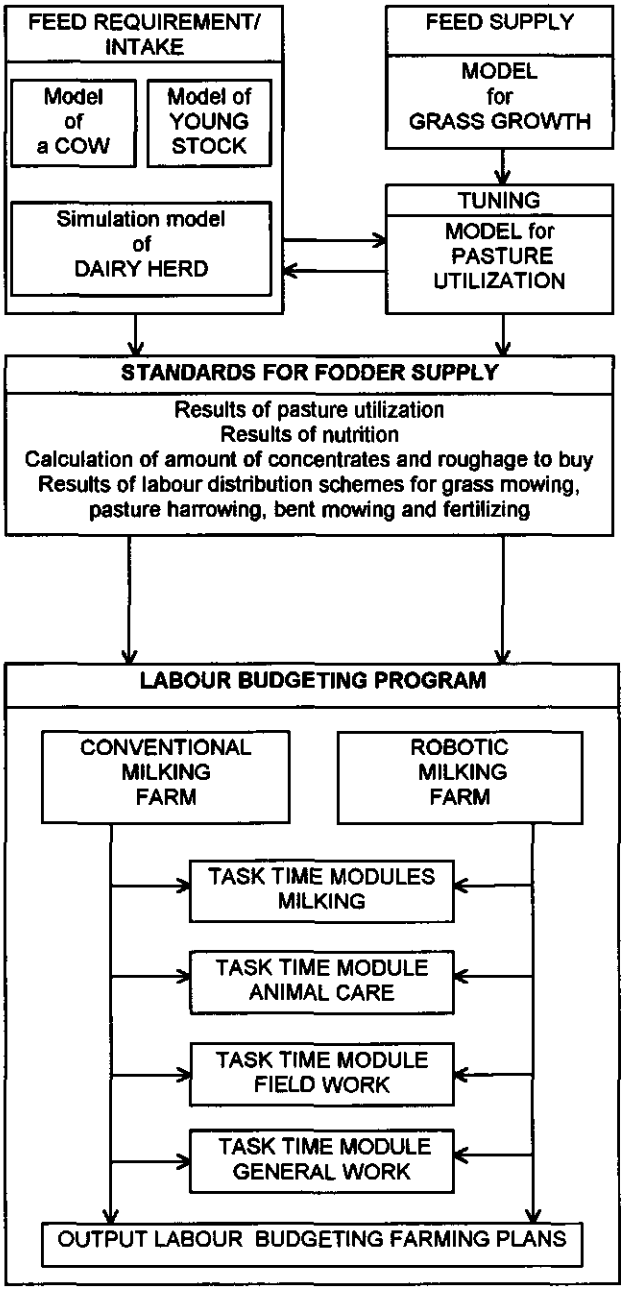

***Fig. 1.** View on the applied programs with integrated simulation models and calculation modules for the determination of the labour requirement on conventional and robotic milking dairy farms*

The SFS program supplies the labour budgeting program ARBGRO with the following input data (Fig.1) : (1) labour distribution schemes for tasks such as mowing, pasture harrowing and fertilizing that are expressed in percentages of the farmland that has to be mowed, harrowed or fertilized in certain periods of the year; (2) pasture utilization gives the division of the grassland according to category of animals : cows, yearlings and calves; (3) nutritional requirements are used to calculate the work for feeding the animals in winter and summer periods; (4) calculation of the amount of concentrates and roughage to buy gives an indication of the shortage of fodders. IMAG-DLO developed a simulation model that calculates the number of animals in each age class and in each two-week period of the year. The assumptions used in the model are comparable with those of the 'dairy herd model' of Mandersloot and van der Meulen (1991) (see also Sonck and van Elderen (1996)).

To derive the labour requirement and supply for a whole year (tactical level), IMAG-ARBGRO farm labour budgeting was used. A labour budget makes a comparison of labour demand for operations and the labour supply for the farm as a whole. Budgeting is a way of assigning operations (the demand) to periods within given constraints. Therefore, one uses in IMAG-ARBGRO 26 two-week periods or 13 four-week periods along with the assignment of operations to a limited number of these periods (Kroeze, 1975). This planning system shows the shortage or surplus of labour that occurs in each period. It also takes into account the workability of all operations. With IMAG-ARBGRO five different classes of workability are distinguished, ranging from class 1 (perfect weather conditions necessary) to class 5 (weather conditions not relevant). A workability class is assigned to each operation. To calculate the labour demand for the operations to be executed on a conventional or robotic milking dairy farm, the labour budgeting program makes use of task time modules. The task time modules used for this study are calculation modules for field operations for grassland farming including any transport and storage involved (De Lint, 1972), for animal care (e.g. feeding of cows) (Kroeze and Bosch, 1984), for milking in conventional milking parlours (Sonck et al., 1991), for milking with an automatic milking system (Sonck, 1995; Sonck et al., 1996) and for general work (Halman, 1985). These modules offer the opportunity to compute the task times of all operations under farm-specific circumstances, according to the number of animals, milk production, available mechanization, type and size of the barns, and staff. These modules can be used independently to obtain information about the task times of separate operations, but function in this study as input for the labour budgeting program.

3.2. Farming plans for conventional and robotic milking dairy farms

To investigate the set of objectives mentioned in the introduction, various farming plans (FP) have been defined by choosing starting-points related to the use of farmland (grassland and/or forage maize crops), the annual milk yield per cow and the grazing system. The starting-points of two reference farming plans of conventional milking dairy farms are given in appendices A and B, respectively the FP of a farm where 45 ha of farmland are entirely used for grassland and the FP of another where the available farmland is partly used for grassland (35 ha) and partly for forage maize crops (10 ha). In these two 'reference' FPs, respectively called FP *grassref* and FP *maizeref*, further starting-points are : the annual milk yield of a cow, rated at 7000 kg with 4.40% fat and 3.40% protein; the area-based milk quota being 12 500 kg per hectare; unrestricted grazing i.e. day and night grazing with every 4 days a new plot, applied during the summer period; an automated herringbone milking parlour with 2 times 6 milking units; the labour supply provided by the farmer (2600 hours) and family members (2600 hours). Calculations are based on a 2 + 2 row cubicle house for the dairy cows, individual boxes for calves (< 2 months), slatted floors with a littered lying area for young stock (3-8 months) and a cubicle housing system for young stock (9 - 24 months). Sufficient young stock is kept for a replacement rate of 25% of the herd. Surplus calves were disposed off immediately after birth. We assume yearlings and calves to be grazing day and night during the summer period, respectively with every six and ten days a new plot.

To study the influence of automatic milking on the labour requirement, some of the starting-points stated for the reference FPs have been modified to create several farming plans of robotic milking dairy farms according to the objectives. Table 1 shows the modified FPs where farmland is solely used for grassland. The AMS on the RMDF comprises two milking stalls and, if the AM-CCT method is applied, two selection units are added (Sonck and van Elderen, 1996; Devir, 1995). It is assumed that an increase in milking frequency from 2 to 3 times a day with the AMS results in a 15% higher annual milk yield per cow or in 8050 kg of milk per cow and per year with 4.25% fat and 3.35% protein (Ipema et al., 1987). In the same way, modified farming plans are defined and derived from the reference FP where farmland is partly used for forage maize crops. For the latter FPs the same technical data as in Table 1 are applied. The main difference with the 'grassland' FPs is the land use: 10 hectares of maizeland and 35 hectares of grassland. These FPs are, in analogy with the 'grassland' FPs in Table 1, indicated as *maizeref, maize(U4/70c), maize(U4/80c), etc.*

For all FPs of RMDFs, it is assumed that the young stock are housed and are grazing in the same way as on the CMDFs. Furthermore, it is supposed that the regular maintenance and repairs of the milking robot are done by the service department of the milking robot company.

As the 'Standards for Fodder Supply'-program offers the possibility to choose from different soil types, groundwater levels and nitrogen dressing patterns for grassland, we ought to mention that in either case a moisture-retaining sandy soil and a nitrogen dressing pattern of 300 kg per hectare were chosen. It is assumed that for all farming plans the farmland is completely used for grazing, grass silage or maize silage production, even if there is a forage surplus.

4. Results and discussion

To summarize the operations executed on a conventional (CMDF) or a robotic milking dairy farm (RMDF), the operations are assigned to the following task groups : (1) work for grass silage; (2) care of the grassland; (3) work for maize silage; care of (4) the calves; (5) the yearlings; (6) the cows; (7) milking the dairy cows; (8) general work on the farm. This section is subdivided in four sections according to the objectives.

Table 1. *Technical data of the farming plans where the farmland is entirely used for grassland*

Technical data	*Farming plans*												
	grassref (U4/80c)	*grass (U4/70c)*	*grass (U4/80c)*	*grass (U4+3/70c)*	*grass (U4+3/80c)*	*grass (R4+3/70c)*	*grass (R4+3/80c)*	*grass (R4+6/70c)*	*grass (R4+6/80c)*	*grass (Zg/70c)*	*grass (Zg/80c)*	*grass (Sf/70c)*	*grass (Sf/80c)*
Grazing system	U4	U4	U4	U4+3	U4+3	R4+3	R4+3	R4+6	R4+6	Zg	Zg	Sf	Sf
Annual milk yield per cow (kg)	7000	8050	8050	8050	8050	8050	8050	8050	8050	8050	8050	8050	8050
Milking system	HMP2x6	AMS	AMS	AMS	AMS	AMS	AMS	AMS	AMS	AMS	AMS	AMS	AMS
Milking method winter period	CM2x	CCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x
Milking method transition period	CM2x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x
Milking method summer period	CM2x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	HCT 3x	CCT 3x	CCT 3x	CCT 3x	CCT 3x
Number of cows	80	70	80	70	80	70	80	70	80	70	80	70	80
Number of calves	27	23	27	23	27	23	27	23	27	23	27	23	27
Number of yearlings	25	21	25	21	25	21	25	21	25	21	25	21	25

U4 = unrestricted grazing or day and night grazing with every 4 days a new plot
U4 + 3 = unrestricted grazing with supplementary feeding of 3 kg DM maize silage per day
R4 + 3 or 6 = restricted grazing or overnight housing with supplementary feeding of 3 or 6 kg DM maize silage per day
Zg = zerograzing or day and night housing of cows and feeding with fresh cut grass
Sf = summerfeeding or day and night housing of cows and feeding with roughage
CM = conventional milking in a herringbone milking parlour (HMP) and a milking frequency of 2 times a day
CCT3x = automatic milking with a computer-controlled cow traffic and a milking frequency of 3 times a day
HCT3x = automatic milking with a human-controlled cow traffic and a milking frequency of 3 times a day
AMS = automatic milking system with a two-stalls milking robot

4.1. Effects of farming plans with only grassland and with grassland and maizeland

Table 2 gives the annual labour requirement and its subdivision into the mentioned task groups for two 'reference' CMDFs with unrestricted grazing and for two RMDFs with summerfeeding as grazing system. Here, summerfeeding means that the dairy cows are kept indoors and fed with roughage during the whole year. As a result of the 15% higher milk yield per cow and the sustained milk quota, the number of animals is reduced and the farming plans grass(Sf/70c) and maize(Sf/70c) result in a forage surplus for grass silage of respectively 109 489 kg DM and 123 260 kg DM, whereas the FPs grassref(U4/80c) and maizeref(U4/80c) do not have any forage surplus. Therefore, Table 2 shows the annual labour requirement with and without ignoring the work hours assigned to the forage surplus.

Table 2. *The labour requirement (in hours per year) for different task groups on two conventional milking dairy farms resp. with farming plan grassref(U4/80c) and maizeref(U4/80c) and on two robotic milking dairy farms respectively with farming plan grass(Sf/70c) and maize(Sf/70c)*

Task group	*Farming plan*			
	grassref (U4/80c)	*grass (Sf/70c)*	*maizeref (U4/80c)*	*maize (Sf/70c)*
Grass silage	593	1185 *(1555)	297	723 *(1123)
Care grassland	510	330 *(433)	416	211 *(327)
Maize silage	0	0	83	83
Calves	468	411	468	411
Yearlings	213	174	213	174
Dairy cows	849	911	840	934
Milking	1555	489	1555	489
General work	1003	866	962	845
Annual labour requirement (h)	5182	4366	4834	3870
Relative labour requirement (%)	100.0	84.3	100.0	80.0
Relative labour savings (%)	0.0	15.7	0.0	20.0
Annual labour requirement* (h)	5182	4839	4834	4386
Relative labour requirement* (%)	100.0	93.4	100.0	90.7
Relative labour savings* (%)	0.0	6.6	0.0	9.3

* For these figures, the work hours assigned to forage surplus are not omitted

The labour savings for milking and for care of the grassland are largely absorbed in the supplementary work for grass silage (mowing, teddering, raking, picking-up and ensilage). The labour reduction for FP grass(Sf/70c) amounts to 816 h or 15.7% in comparison to FP grassref(U4/80c) whereas the labour reduction for FP maize(Sf/70c) in comparison to FP maizeref(U4/80c) is higher (964 h or 20.0%) due to the fact that 10 ha is used for forage maize crops instead of for grassland and that the harvest of the maize silage is done by contract workers.

The FPs grass(Sf/70c) and maize(Sf/70c) result however in lower labour reduction when the work hours for the forage surplus for grass silage are included. Table 2 reveals no spectacular differences in annual labour requirement. The FP grass(Sf/70c) and the FP maize(Sf/70c) result in labour savings of respectively 343 h (6.6%) and 448 h (9.3%).

Figs 2, 3, 4 and 5 show the evolution of the labour requirement per two-week period over the whole year for respectively the FPs grassref, grass(Sf/70c), maizeref and maize(Sf/70c). The work hours assigned to the forage surplus are excluded. Comparing Figs 2 and 3 reveals that the use of an AMS combined with summerfeeding will strongly change the distribution of the labour demand. Whereas for the FP grassref, the labour demand is more spread over the year and shows four slight peaks during the summer (period 10 to 20), the labour demand for the FP grass(Sf/70c) is approx. 50 h per period lower during the winter (period 21 to 8) and clearly shows four sharp peaks during the summer. Apart from the confirmation that supplementary work is needed for the maize silage (e.g., fertilizing), the conclusions on the comparison between FPs maizeref and maize(Sf/70c), and from Figs 4 and 5, are analogous to those drawn from Figs 2 and 3. Here, the four labour peaks in FP maize(Sf/70c) are approx. 100 h per period lower than those in FP grass(Sf/70c). This can be explained by the smaller area of grassland in FP maize(Sf/70c) which consequently results in a lower labour input for grass silage and care of the grassland.

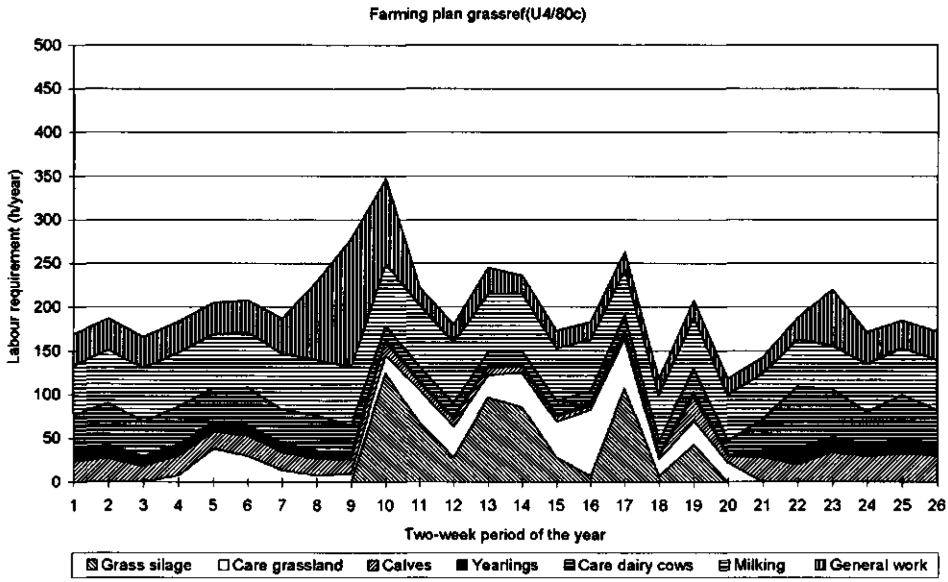

Fig. 2. Labour requirement per two-week period of the year for different task groups on a conventional milking dairy farm with farming plan grassref(U4/80c) (45 ha of grassland)

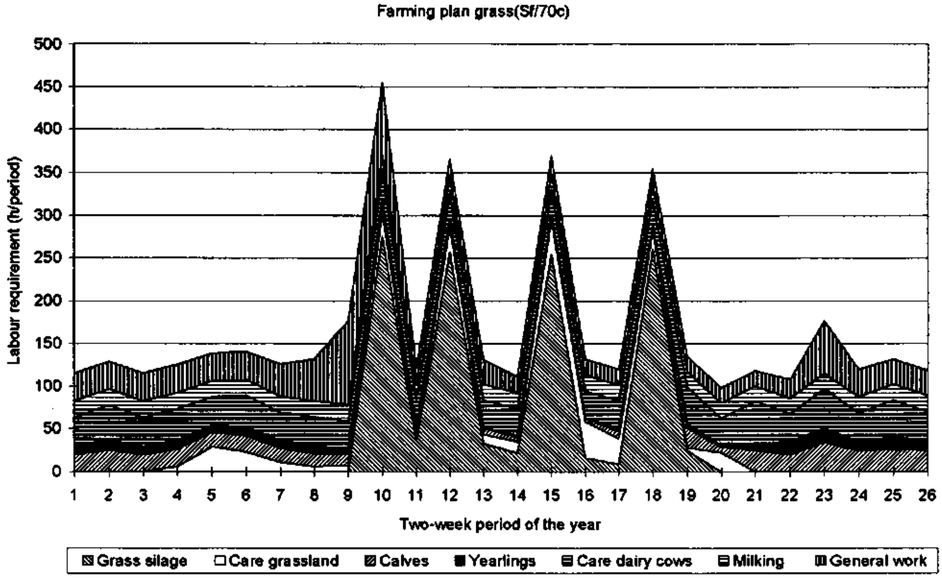

Fig. 3. Labour requirement per two-week period of the year for different task groups on a robotic milking dairy farm with farming plan grass(Sf/70c) (45 ha of grassland)

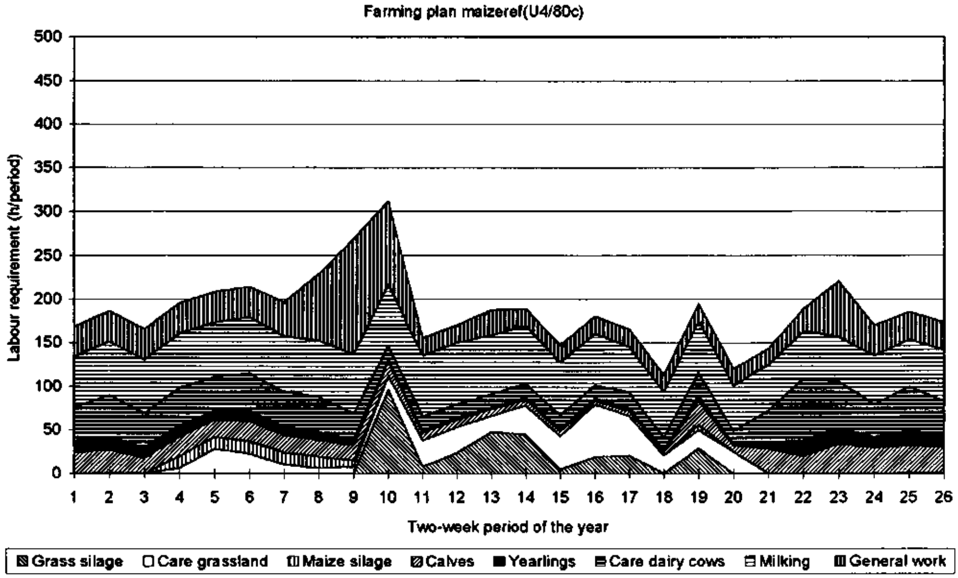

Fig. 4. Labour requirement per two-week period of the year for different task groups on a conventional milking dairy farm with farming plan maizeref(U4/80c) (35 ha of grassland and 10 ha of forage maize crops)

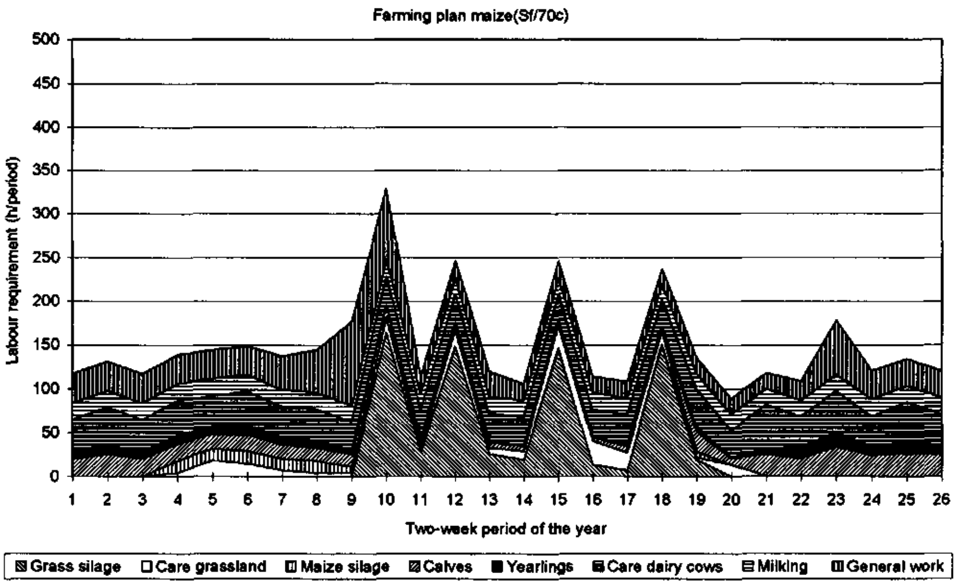

Fig. 5. Labour requirement per two-week period of the year for different task groups on a robotic milking dairy farm with farming plan maize(Sf/70c) (35 ha of grassland and 10 ha of forage maize crops)

4.2. Effects of grazing systems applied with automatic milking

Table 3 gives the labour requirement for FPs of RMDFs with 45 ha of grassland and with different grazing systems compared to the labour requirement for the 'reference' CMDF with FP grassref and a grazing system U4 'unrestricted grazing with every four days a new plot'. In either FP, it is supposed that the milk quota is 560 tonnes.

For the figures where the work hours for forage surplus are omitted, all farming plans of RMDFs result in a labour reduction of at least 15.7% or approx. 800 h per year. The farming plans with restricted grazing and supplementary feeding of maize silage, namely grass(R4+3,70c) and grass(R4+6/70c) result in the largest labour savings : 22.1%(1144 h) and 22.2% (1152 h). If the work hours for the forage surplus are included, the RMDFs with grazing system U4(+3) and R4(+3 or +6) have a higher labour input for grass silage than FP grassref. A higher milk yield per cow appears to go together with higher grass intakes per animal, but, because of the smaller herd size, with a lower grass intake for the herd as a whole during the grazing period. Consequently, with a higher individual milk yield as a result of the increased milking frequency with automatic milking, more grass will be available for forage production and more grass silage can be made for the winter period. Hence, more labour is required for the task group grass silage. Supplementary feeding of 3 or 6 kg DM maize silage will strengthen this effect. This supplementary feeding of maize silage will decrease the grass intake of a cow and of the herd and consequently more grassland will be available for forage production. Here again, the labour demand for grass silage will increase. In Table 3 we skip the work for the forage surplus, because in practice the farmer can use the farmland for other purposes than grass silage. This results in lower figures for grass silage production. The RMDFs with grazing system U4(+3) and R4(+3 or +6) are forced to apply automatic milking with a human-controlled cow traffic (AM-HCT), which explains the higher labour demand for milking the cows in comparison to grazing systems Zg and Sf.

Table 3. *The labour requirement (in hours per year) for different task groups and for farming plans with different grazing systems. A comparison between a conventional milking dairy farm (grassref) and robotic milking dairy farms with 45 ha of grassland. In either farming plan, the milk quota is 560 tonnes*

Task group	*Farming plan*						
	grassref (U4/80c)	*grass (U4/70c)*	*grass (U4+3/70c)*	*grass (R4+3/70c)*	*grass (R4+6/70c)*	*grass (Zg/70c)*	*grass (Sf/70c)*
Grass silage	593	633	626	594	571	671	1185
	*(593)	*(641)	*(753)	*(820)	*(883)	*(732)	*(1555)
Care grassland	510	494	398	322	304	364	330
	*(510)	*(501)	*(478)	*(445)	*(470)	*(397)	*(433)
Calves	468	411	411	411	411	411	411
Yearlings	213	174	174	174	174	174	174
Dairy cows	849	709	717	773	806	1208	911
Milking	1555	951	951	828	828	489	489
General work	1003	928	930	936	936	858	866
Annual labour requirement (h)	5182	4300	4207	4038	4030	4175	4366
Relative labour requirement (%)	100.0	83.0	81.2	77.9	77.8	80.6	84.3
Relative labour savings (%)	0.0	17.0	18.8	22.1	22.2	19.4	15.7
Annual labour requirement* (h)	5182	4315	4414	4387	4508	4269	4839
Relative labour requirement* (%)	100.0	83.3	85.2	84.7	87.0	82.4	93.4
Relative labour savings* (%)	0.0	16.7	14.8	15.3	13.0	17.6	6.6

* For these figures, the work hours assigned to forage surplus are not omitted.

If the work hours for the forage surplus are included, zerograzing results in the greatest labour reduction (17.6%), which may seem somewhat surprising with respect to the figures of summerfeeding. As the cows stay indoors during the whole year with zerograzing, fully automatic milking can be applied throughout the year. This explains the low labour demand for milking the cows. Zerograzing means that the cows are fed fresh cut grass during the summer period which requires supplementary work for mowing, picking-up and distribution of grass in the barn and explains the higher figure for care of the dairy cows in comparison to this of FP grassref. However, zerograzing diminishes the labour input for grassland care, as grass harrowing and bent mowing are not needed.

Summerfeeding allows also the application of the AM-CCT milking method but, as seen in Table 2 and Fig. 3, the labour savings from milking and grassland care are absorbed by grass silage production. Summerfeeding results in the lowest labour reduction with as well as without inclusion of the work hours for forage surplus. If the grazing system of the RMDF remains the same as in CMDF, the labour demand decreases with approx. 880 h per year or 17.0%.

Table 4 gives the labour requirement for RMDF farming plans with 35 ha of grassland and 10 ha of forage maize crops and with different grazing systems compared with the labour requirement for the 'reference' CMDF with FP maizeref and the grazing system U4. A comparison between Tables 3 and 4 reveals that the same conclusions can be drawn from the FPs 'maize' as from the FPs 'grass' as far as the effects of the various grazing systems on the annual labour requirement are concerned. However, farming plan maize(Sf/70c) results here in the greatest labour reduction (20% or 964 h). We have to bear in mind that only this farming plan has a forage surplus. When the work hours for forage surplus are not ignored, FP maize(Sf/70c) results in a labour saving of only 9.3% or 448h. Comparing the FPs with the same grazing systems of Tables 3 and 4, the FPs 'maize' have a lower annual labour input than the FPs 'grass', i.e. up to 300 h. The figures of Table 4 demonstrate that the introduction of the AMS on a farm with a FP 'maize' results in labour savings that are slightly lower than on a farm with a FP 'grass' and with exclusion of work hours for forage surplus. When the work hours for forage surplus are not ignored the zerograzing system seems to be the best alternative as far as labour input is concerned. Labour savings amount then to 18.8% or 911 h.

Table 4. *The labour requirement (in hours per year) for different task groups and for farming plans with different grazing systems. A comparison between a conventional milking dairy farm (maizeref) and robotic milking dairy farms with 35 ha of grassland and 10 ha of forage maize crops. In either farming plan, the milk quota is 560 tonnes*

Task group	*Farming plan*						
	maizeref (U4/80c)	*maize (U4/70c)*	*maize (U4+3/70c)*	*maize (R4+3/70c)*	*maize (R4+6/70c)*	*maize (Zg/70c)*	*maize (Sf/70c)*
Grass silage	297	332	436	493	573	377	723 *(1123)
Care grassland	416	462	410	389	363	332	211 *(327)
Maize silage	83	83	83	83	83	83	83
Calves	468	411	411	411	411	411	411
Yearlings	213	174	174	174	174	174	174
Dairy cows	840	736	743	798	834	1224	934
Milking	1555	951	951	828	828	489	489
General work	962	901	887	893	895	833	845
Annual labour requirement (h)	4834	4050	4095	4069	4161	3923	3870
Relative labour requirement (%)	100.0	83.8	84.7	84.2	86.0	81.2	80.0
Relative labour savings (%)	0.0	16.2	15.3	15.8	14.0	18.8	20.0

* For these figures, the work hours assigned to forage surplus are not omitted

4.3. Effects of the milk quota

The question to what extent labour input will change on RMDF if the milk quota are extended in order to maintain a herd size of 80 cows remains. Table 5 gives the labour requirement for different task groups and for FPs with different grazing systems and with 45 ha of grassland, assuming a rise in the milk quota or a herd size of 80 cows. Comparing the FPs of the RMDF in Table 5 with the FP grassref, the highest labour reduction is obtained with the FP maize(R4+6/80c) (14.1% or 732 h) and or 1371 h compared to FP grassref with CW. When the milk quota are extended in order to hold on to a herd size of 80 cows, the grazing systems R4+3 and R4+6 are competitive. Zerograzing requires approx. 100 h more than the systems with restricted grazing.

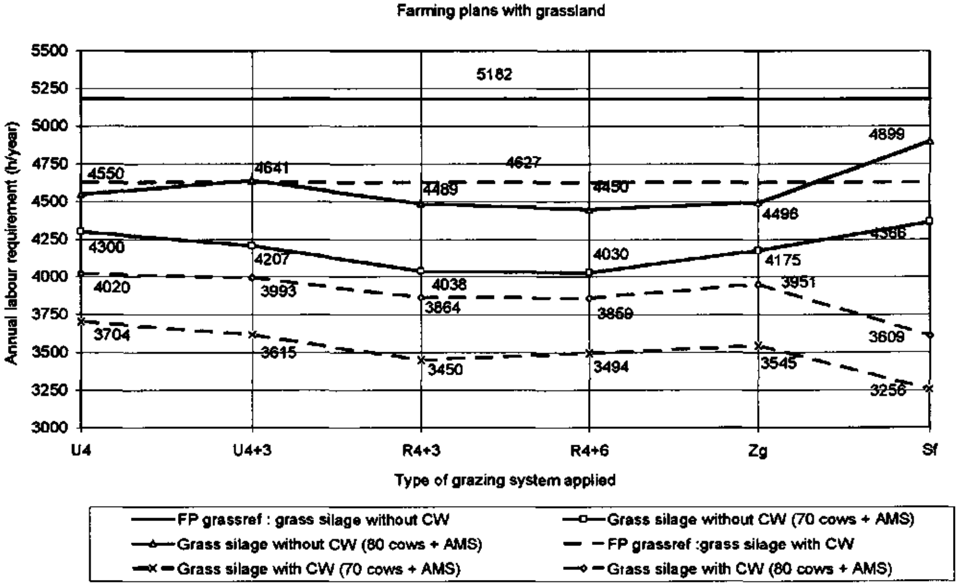

***Fig. 6.** Annual labour requirement (in hours per year) on conventional and robotic milking dairy farms with and without contract work (CW) for grass silage production. Farming plans with 45 ha of grassland and with different grazing systems*

When the milk quota are maintained at the level of 560 tonnes (70 cows), the zerograzing system requires a lower labour input than the grazing systems with unrestricted grazing. This can be explained by the labour savings obtained with fully automatic milking with zerograzing in contrast to the grazing systems where cows are grazing during the summer period and AM-HCT has to be applied. Farming plans with restricted grazing require approx. 130 h less work for milking than FPs with unrestricted grazing. Therefore, the restricted grazing system requires also a lower labour input than the zerograzing system.

Fig. 7 allows to draw similar conclusions as for Fig. 6. However, the absolute differences in labour requirement between the FPs maize with and without CW for grass silage production are smaller for the FPs maize than for the FPs grass. Here, the grazing systems R4+3, R4+6 and zerograzing for FPs with CW and with an extended milk quota are competitive. For all FPs maize with CW, the summerfeeding is the best alternative, e.g. FP maize(Sf/70c) with CW results in a labour reduction of 29.9% or 1361 h.

Fig. 8 shows the distribution of the labour requirement over the 26 two-week periods for a robotic milking dairy farm with FP grass(Sf/70c) with the use of contract work for grass silage production. In comparison with Fig. 3, the labour demand is more regularly distributed over the year and never

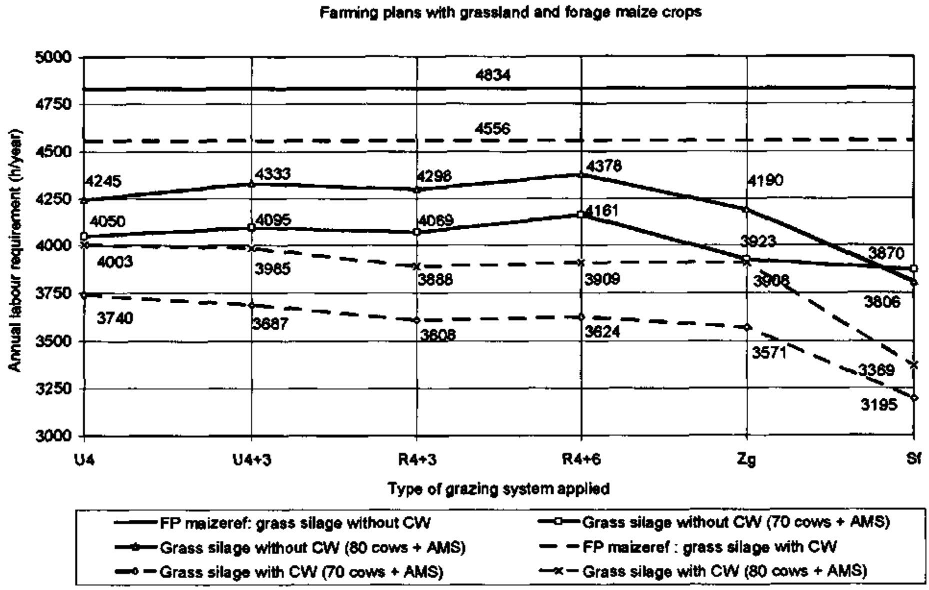

Fig. 7. *Annual labour requirement (in hours per year) on conventional and robotic milking dairy farms with and without contract work (CW) for grass silage production. Farming plans with 10 ha of farmland for forage maize crops and 35 ha of grassland and with different grazing systems*

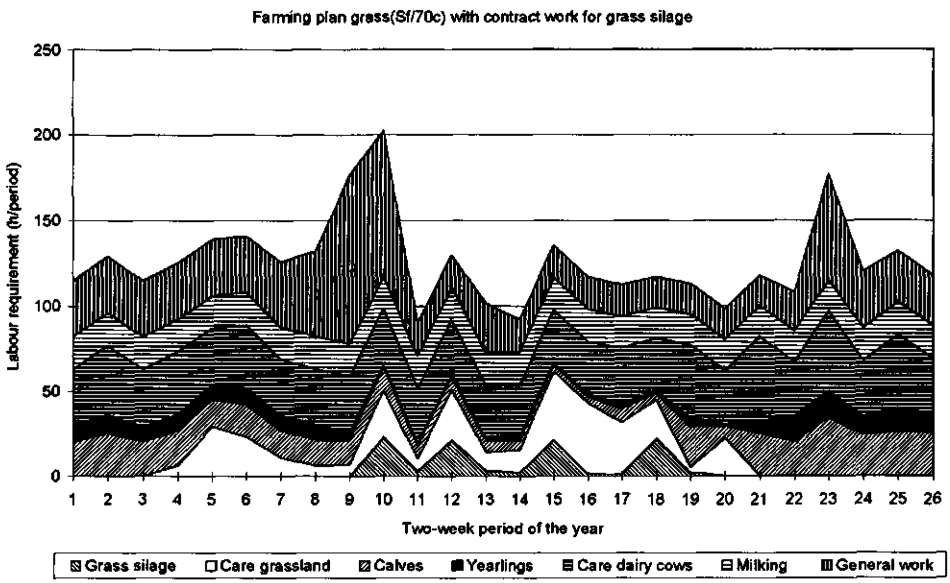

Fig. 8. *Labour requirement per two-week period of the year for different task groups on a robotic milking dairy farm with farming plan grass(Sf/70c) and with the employment of contract work for grass silage production (45 ha of grassland)*

exceeds the level of 250 man-hours in a two-week period. There are only three periods where the labour requirement exceeds the level of 150 man-hours in a two-week period.

It is clear that other strategical choices can be made to create other farming plans than those considered in this study or to investigate the influences of automatic milking under other circumstances such as : (1) what if the young stock is permanently in confinement; (2) what if the expected 15% increase in milk production is not reached; (3) what if not all cows are suited for automatic milking and more young stock needs to be kept; etc. In this paper we have tried to present the most important farming plans in which automatic milking is involved, together with their pros and cons. From this a number of conclusions were drawn which are recapitulated under 5.

5. Conclusions

By combining two programs, namely the IMAG-ARBGRO labour budgeting program, extended with task time modules for automatic milking and the program 'Standards for Fodder Supply', it was possible to calculate the labour budget of robotic milking dairy farms with different grazing patterns and to compare these farms with conventional milking dairy farms.

With respect to the four objectives mentioned in the introduction, the following conclusions can be drawn.

(1) From an operational point of view (Devir, 1995), it appeared normal until now to combine automatic milking with summerfeeding as 'grazing system' while the cows are kept indoors the whole year in the vicinity of the AMS. If, in this case, the operations for grass silage production are executed by the farmer and his relatives, then the labour savings obtained with milking will be mainly absorbed by the surplus of work for producing grass silage. Labour savings of 6.6% and 9.3% were found respectively for a farm with only grassland and for another with grassland and land for forage maize crops. Ignoring the work for forage surplus, the labour savings amount to 15.7% for FP grass and 20.0% for FP maize, both with summerfeeding. Labour distribution over the whole year on a robotic milking dairy farm with summerfeeding is characterized by four sharp peaks during the summer period and a low labour input (approx. 125 h per two-week period) outside these peak periods. These labour peaks will require the availability of contract workers or a surplus of labour input from the farmer and his relatives.

(2) Comparing various grazing systems for FPs with only grassland and with the same milk quota, we conclude that zerograzing results in the greatest labour reduction (17.6%) and summerfeeding in the smallest reduction (6.6%). Disregarding the additional work of forage surplus, all grazing systems combined with automatic milking result in a labour reduction of at least 15.7% with a maximum of 22.2% for the grazing system R4+6.

Comparing the various grazing systems for FPs with grassland and maizeland and with unchanged milk quota, zerograzing again results in the greatest labour reduction (18.8%) and summerfeeding in the smallest reduction (9.3%). However, ignoring forage surplus work, summerfeeding results in the greatest labour reduction (20% or 816 h).

(3) If the milk quota are extended in order to keep the same herd size, the same conclusions can be drawn as above, as far as differences between the grazing systems are concerned. However, the labour reduction amounts only to 1.8 to 14.1% for FPs grass and to 9.5 to 21.3% for FPs maize.

(4) Farmers using contract workers for grass silage production will profit the most of automatic milking in terms of labour reduction. For these farms, the labour reduction amounts to 20.0 (923 h) to 29.6% (1371 h) for farming plans with only grassland and with contract work and to 17.9 (816 h) to 29.9% (1361 h) for farming plans with grassland and maizeland and with contract work. On these farms, automatic milking combined with summerfeeding appears to be the best alternative.

As overall conclusion, we stress that, in a comparison of different grazing systems, the labour requirement and labour savings with automatic milking will strongly depend on the decisions made by the farmer with respect to the use of contract work, the use of the available farmland and on the milk quota. In addition, labour savings will largely depend on a successful functioning of the AMS, i.e. a smooth cow traffic towards the milking point, a failure-free working of the milking robot and a user-friendly interface for the farmer in the AMS management programs.

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Appendix A : Data of a farming plan of a farm where the farmland is fully used for grassland

This farming plan is further indicated as *FP grassref*

Land use	45 ha of grassland (for pasturing and mowing)
Herd size	80 dairy cows, 25 yearlings, 27 calves
Stocking rate	2.8 GDE Remark : GDE = GraasDierEenheden (Dutch) = one grazing animal unit refers to the feed requirement of one dairy cow with a milk production of 6000 kg
Housing	Dairy cows : 2 + 2 row cubicle house Calves (< 2 months) : individual boxes Young stock (3 - 8 months) : slatted floors + littered lying area Young stock (9 - 24 months) : cubicle housing system
Milking system	Automated herringbone milking parlour with 2 times 6 milking units and with automatic cluster removal. One person milks the cows.
Labour supply	Farmer + assistance of the family Assistance of the family is mostly required for the following activities: (rotational) grazing, housing, calving (when problems), care of little calves (< 2 months), feeding young stock (< 9 months), making silage/hay, cleaning milking parlour and tank house, contact with veterinary surgeon and artificial insemination, bookkeeping, cleaning farm/farmyard and mostly the replacement of the farmer when he is absent (illness, other duties)
Land division	27 ha on house block, 12 ha at 750 m, 6 ha at 1500 m
Storage of fodder	Grass silage and (bought) maize silage in clamp silos, concentrates in silo
Storage of manure	Stable manure on manure yard, slurry in the slurry cellar under the cowhouse, fertilizer in silos

Grazing system	U4 for cows = unrestricted grazing or night and day grazing with every 4 days a new plot; U6 for yearlings = idem with every 6 days a new plot; U10 for calves = idem with every 10 days a new plot
Feeding system	Loading silage from clamp silo with a silage unloader-cutter with spreader (capacity 2 m^3); transport on farmyard; distribution of the silage at the feeding fence. Concentrates are distributed by means of automatic concentrate dispensers.
Contract work	prepare seedbed and reseed grassland, weed control
Mechanization	2 tractors 1 four-wheel farm wagon (4 tonnes) 1 self-loading pick-up trailer with dispensing system, driving speed 6 km/h 4 electric mixers for slurry, with timers (7.5 kW) 1 pasture scraper (5 m) 1 fertilizer distributor (centrifugal system with two discs, 800 l, working width 12 m) 1 vacuum spreader tank (6 m^3) + sod dunging system (working width 5 m) 1 front loader 1 rotating plough with 3 ploughshares, 5 km/h, working width 1.20 m 1 harrow, float, roller (working width 3 m, driving speed 5 km/h) 1 rotary mower (working width 2.40 m, driving speed 8 km/h) 1 rotary tedder (working width 6.4 m, driving speed 7 km/h) 1 rotary rake (working width 6.4 m, driving speed, 7 km/h) 1 silage unloader-cutter with spreader (capacity 2 m^3) 1 box for claw treatment 1 high pressure cleaner 1 irrigation system (hose installation 90 mm : 50 m^3/h) 1 programmed distributor of concentrates (with 3 feeder dispensers in the cowhouse) 1 milking installation (herringbone milking parlour with 12 milking stalls with milking units and milking pipelines and milk cooling tank) - ditch cleaning installation - wagons for feeding and wheelbarrows - the normal (hand)tools (e.g. forks, scoops, etc.)
Buying fodders	maize and grass silage if necessary

Appendix B : Data of a farming plan of a farm where the farmland is partly used for grassland and partly for forage maize crops

This farming plan is further indicated as *FP maizeref*
The most important differences with *FP grassref* are stated.

Land use	35 ha of grassland (for pasturing and mowing) and 10 ha of land for forage maize crops
Land division	27 ha on house block, 8 ha at 750 m, 10 ha at 1500 m
Storage of fodder	Grass silage and maize silage in clamp silos, concentrates in silo
Contract work	Prepare seedbed and reseed grassland, weed control Sowing and harvest of maize
Buying fodders	maize and grass silage if necessary

The herd size, stocking rate, housing, milking system, labour supply, storage of manure, grazing system, feeding system and mechanization of farming plan *maizeref* are equal to those of *grassref.*

Chapter 8

General discussion and conclusions

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1. Background and settings

The research described in this dissertation is focused on the effects of the integration of the milking robot in a dairy farm on the labour organisation at operational and tactical level. Attention was paid to the future requirements concerning human labour and labour (re)organisation with respect to the complex interaction between the cows and an automatic milking system (AMS) on a robotic milking dairy farm (Chapter 1).

As the automatic milking system has to replace fully or partly the milker and the milking parlour, it involves the automation of all milking operations. From an evaluation of dairy technology we concluded that more or less adequate technical solutions for the automation of each milking operation performed in conventional milking parlours are nowadays available (Chapter 2). Future research and practical experience must contribute to the further optimisation of the techniques and their integration in the AMS. Some of the developed devices do not always attain the same degree of accuracy as the milker does in his work, so detection and cleaning of dirty teats require further research to develop effective devices.

An AMS comprises a milking robot with one or more milking stalls, facilities in the cowshed to control the cow traffic towards the milking robot, an expert system that controls and makes decisions related to cow individual milking frequency and concentrate and even roughage supplementation (Devir, 1995; Ipema and Rossing, 1987), a system for automatic detection and registration of illness and oestrus (Schlünsen et al., 1987; Maatje et al., 1992) and a management system that presents the information in a convenient way to the farmer and that spurs him on to take decisions and to come into action. It is clear that an AMS offers tools to monitor, to control and thus to manage a dairy herd.

The prospects of automatic milking for the farmer in comparison to conventional milking are a lower total labour requirement, a lower work load, task enlargement and enrichment and a more flexible labour planning. Automatic milking may also result in a weaker bond to the milking job and the farm and may offer opportunities to upgrade farm management thanks to an important package of information obtained from an AMS that is equipped with several sensors (Sonck, 1992). Farm management on robotic milking dairy farms will in the future be characterized by possibilities to detect abnormalities and to react more quickly than on conventional milking dairy farms. For instance, earlier detection of affected udders may set a trend for reduced somatic cell counts and fewer bacterial infections when milking is performed three times a day (Waterman et al, 1983). Automatic milking offers also opportunities to manage the dairy cow on an individual basis which may improve its health and welfare (Maltz and Metz, 1994) (Chapter 2).

In the determination of the amount of human labour that can be replaced by the milking robot, the capacity of the milking robot forms an indispensable basis for calculations of labour requirement with automatic milking. Therefore, we first established in an operational research the milking capacity of a milking robot by focusing on the interaction milking robot - dairy cow and by excluding the human role in the milking process. The milking process was studied by means of cycle analyses which resulted in the definition of a formula of tuning (Chapter 3). Though automatic milking is supposed to be an autonomous working process, the farmer or 'milker' still has to perform a number of milking operations. To derive these milking operations, we studied the interactions farmer - milking robot and farmer - dairy cow. From this study, as described in Chapter 4, we developed a task time module which allows to calculate the labour requirement for automatic milking combined with different grazing systems. A grazing system refers here to a specific time distribution of 'keeping cows in- or outdoors' on daily and yearly basis.

From a labour organisational point of view, the success of automatic milking will depend on the degree of independent functioning of the total system. Irregularities with the cow traffic in the cowshed as well as with the milking robot itself may occur and can disturb the farmer's daily labour planning. Some labour plannings may delay the intervention of the farmer to the AMS when failures occur and can adversely affect the milking process. To study the interdependency of automatic milking and the operational labour planning of the farm, a dynamic stochastic simulation model of automatic milking systems was built (Chapter 5). The model allows to judge the effects of irregularities on the milking process for different AMS arrangements and under various degrees of availability of the farmer to the system. The simulation model has been extended with a program which enables to judge the quality of operational labour planning and to calculate the labour requirement for the milking job under different AMS management strategies (Chapter 6).

By combining two existing programs, namely the IMAG-ARBGRO labour budgeting program, extended with task time modules for automatic milking and the program 'Standards for Fodder Supply', it was possible to calculate the labour budget of robotic milking dairy farms with various grazing systems. The purpose was to compare labour requirement and labour organisation at tactical level on robotic milking dairy farms with those on conventional ones.

The aim of this general discussion now is to review and discuss the results obtained from labour time studies, task time programs and simulation models. Attention is paid to the application of knowledge obtained from this modelling approach on potential commercial robotic milking dairy farms. In this general discussion we will consider two main AMS management strategies : (1) the fully-automatic strategy with computer-controlled cow traffic based on voluntary visits of the cows to the milking point during 24 h of the day, a cubicle house with restricted one-way cow traffic and individual concentrate supplementation and milking (AM-CCT) and (2) a semi-automatic strategy with human-controlled cow traffic based on milkings at fixed moments of the day, under supervision of the farmer and either individual concentrate supplementation by means of computerized self-feeders or group feeding using a total mixed ration (Maltz et al., 1992) (AM-HCT).

2. The milking capacity of a milking robot

The capital investment involved in the realisation of an AMS deserves a detailed forecast of its capacity and possibilities for improvement. We developed a method for an easy and quick determination of the milking capacity with different arrangements of a milking robot. We found that the capacity of current AMS arrangements can be improved by changing the sequence of certain activities and by programming the simultaneous execution of some other activities such as the simultaneous opening of the entrance doors of the milking stall and the milking parlour. Idle times for cow and robot as well as the total cycle duration are thus shortened (Sonck and Donkers, 1995).

In the AM-CCT method the capacity of the milking robot determines the number of milkings per day. The capacity is most important in the AM-HCT method where it determines also the time that the milker has to monitor and eventually assist in the milking process. Here, the milker assembles the herd in a collecting yard before milking, starts the system and for the remaining time has only a supervisory function. Dairy farmers who prefer to graze their cows during summer, will have to follow this working method. The same applies for milking separated cows which fail automatic teatcup attachment in the AM-CCT method (Chapter 6). In this context, the choice of the automatic milking arrangement and the corresponding milking capacity with respect to herd size and aimed milking frequency have to be considered. With regard to Fig. 1, the AM-HCT method calls for integration of a milking robot in conventional milking parlours by using the existing milking stalls.

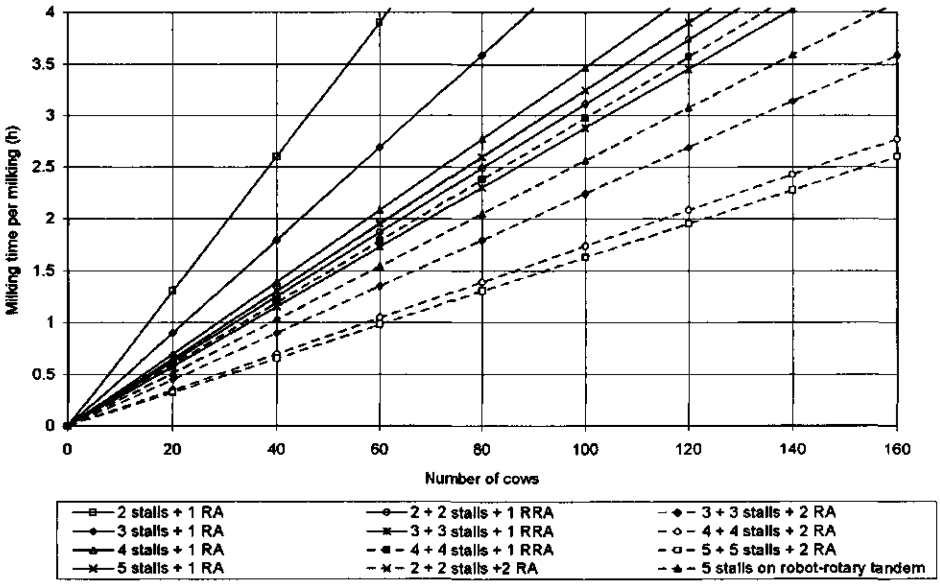

Fig. 1. *The milking time per milking for different herd sizes, a milking frequency of three times a day and with the AM-HCT method. The formula of tuning to determine the milking capacity has been used under improved working conditions of the milking robot. RA = robot arm; RRA = rotary robot arm Remark : line of (5 stalls + 1 RA) coincides with line of (2 + 2 stalls + 2 RA)*

Fig. 1 allows to derive the AMS arrangement for a certain herd size assuming that the milking time may not exceed a maximum time. If we assume 2 h as maximum milking time per milking, a herd of 40 cows requires 3 stalls + 1 RA , of 60 cows requires 4 stalls + 1 RA, of 80 cows requires 3 + 3 stalls + 2 RA or 5 stalls on a robot-rotary tandem, of 100 and 120 cows requires 4 + 4 stalls + 2 RA or 5 + 5 stalls + 2 RA. For a herd size in excess of 120 cows the milking time exceeds 2 h. Raising the number of milking stalls does not increase the milking capacity because the milking robot arm is not able to serve all cows in time. Herd sizes over 120 cows can better be split into two groups each supplied with a convenient AMS arrangement.

The AMS arrangements presented in Fig. 1, with the exception of the two- and three-stalls AMS, are yet not commercially available. The higher capacity of these arrangements requires more attention in future research, as well as the possibilities to integrate a milking robot in conventional milking parlours (Chapter 6). Furthermore an economic evaluation of these AMS arrangements is also essential.

3. Reduction in labour requirement for the milking job with automatic milking

Of all the jobs that have to be performed on a dairy farm, it is obvious that the milking job is the most affected by the introduction of an AMS. The final goal of automatic milking is to discontinue the continuous presence of the herdsman in the milking parlour.

With the AM-HCT method the milker's job is restricted to make ready and put away activities. For the observed farm with approx. 50 cows, the make ready and put away activities took 24.75 min/milking (0.48 min/cow/milking) when the cows were indoors and 43.90 min/milking (0.85 min/cow/milking) when the cows had to be collected from the pasture (Chapter 4). Maton et al. (1985) mentioned that the labour requirement for the make ready and put away activities of conventional milking amounted to 0.52 and 0.91 min/cow/milking for resp. winter and summer. Application of the AM-HCT method will only slightly reduce the labour required for these activities of the milking job when compared to conventional milking. The greatest labour reduction with this method can be realized during the milking proper. Although the milking robot was not yet fully optimized during our observations (March-June 1993 : teatcup attachment score with robot was only 73%), AMS independency of human interventions amounted already to 90% of the milking time. The milker had to work during 10% of the milking time. Fig. 1 allows to derive the labour requirement for the milking proper. Considering the current results (automatic teatcup attachment score 95% - 99%, pers. comm. Hogewerf, 1996) it is expected that the AMS will only require a regular verification by the farmer during the milking proper and that the milker will only need to work during 2 to 5% of the milking time.

Automatic milking with human-controlled cow traffic is a suitable way of milking, not only in the introductory phase of an AMS on a farm, but also when a combination of automatic milking and pasturing is preferred. The AM-HCT method calls for a milking robot with a capacity that guarantees a milking time equal to or shorter than the conventional milking time. For large herds a high capacity of the AMS and/or a division of the herd in smaller groups are advisable as this can prevent long waiting times for the cows in the waiting area (Stefanowska et al., 1995). The AM-HCT method can be a convenient solution for farmers who want to exclude the risk to be disturbed at any moment of the day by cow traffic problems or technical problems. The farmer has fixed and thus exactly known periods in which he needs to be available. In addition, the layout of the cowshed plays a minor role with the AM-HCT method contrary to AM-CCT (Winter et al., 1992; Ketelaar-de Lauwere, 1992; Metz-Stefanowska et al., 1993). When applied throughout the year the AM-HCT method with a milking frequency of three times a day results in physical labour savings for the milking job of 37.9% compared to conventional milking (Chapter 4).

A completely autonomous milking process with a computer-controlled cow routing (AM-CCT) in the cowshed was however at the origin and remains the main goal of automatic milking. A standard work routine for the fully automatic method could be derived from the semi-automatic method. Starting-up procedures, cleaning tasks and a regular control during the day return in this method. The AM-CCT method results in a larger labour reduction (66.1%) for the milking job than the AM-HCT method considering a milking frequency of three times a day and a smoothly working milking process without failures or repairs of the AMS (Chapters 4 and 5).

4. Effects of automatic milking on the labour organisation at operational level

In general the farmer can allocate his time to milking job, non-milking jobs, personal care and social activities. Two kinds of operations can be distinguished in the milking job using automatic milking viz. planned and unplanned milking operations. Unplanned milking operations include (1) repair of robot failures, (2) bringing cows that exceed a maximum milking interval to the milking point and (3) interventions for cows which fail automatic teatcup atttachment. Malfunctioning of the AMS will determine the occurrence of unplanned milking operations which can disturb the daily labour planning. On the other hand, the daily planned tasks during which the farmer cannot be disturbed and is unavailable to the AMS, will delay unplanned milking operations and therefore negatively affect AMS functioning. To study the interdependency of automatic milking and labour planning at operational level, a dynamic stochastic simulation model (Chapter 5) and a program for labour planning quality (Chapter 6) were developed.

From the results of the simulation model, we learned that an AMS with two milking stalls can serve a herd of up to 80 cows with AM-CCT and a milking frequency of three times a day. Therefore, our experiments were executed with a herd of 80 cows and a two stalls AMS with two selection units. Our experiments indicated that the chosen AMS management strategy will strongly determine the absolute and relative importance of the labour requirement for planned and unplanned milking operations. Labour savings for the milking job (see previous section) can be less with the occurrence of unplanned milking operations. For cows that exceed their maximum milking interval it was found that bringing these in groups to the AMS 5 to 6 times a day, results in a reasonable labour requirement for this operation and acceptable milking intervals. This results in few interruptions of other jobs and activities but more delays than when cows are brought individually or in groups during three fixed periods of the day. *Group treatment* is preferable with respect to the low labour requirement, the low impact on labour planning and the negligible negative effect on the average milking interval and the milk production (Sonck et al., 1996). The farmer will have to learn how the cows behave in the cubicle house and depending on their visiting pattern and production level he has to choose the maximum allowable milking interval. The choice of the maximum milking interval has a marked influence on the number of cows that need to be brought to the AMS and consequently, on the labour requirement of this operation. From recent field tests (Devir, 1995) it was concluded that cows can be milked at least 4 times a day almost without the need to be brought to the selection unit thanks to a restricted one-way path or a consistent milking and concentrates reward system.

One of the most important concerns of potential robotic milking dairy farmers is how to deal with robot failures. Robot failures and repair are defined as unplanned milking operations. At the moment, no data on machine downtime or repair time are available. However, the simulation model makes it possible to study the effects of robot failures on the quality of the milking process for different degrees of availability of the farmer or the maintenance service to the system. The results show that a permanently available maintenance service is very important to guarantee the quality of the milking process, especially on those farms where the AMS already operates at the limit of its capacity. We learned that the milking process will benefit more from a farmer who is able to repair most of the robot failures himself and without delay than from one who always immediately calls in the maintenance service of the robot manufacturer. In simulation experiments, we found that the availability of the farmer during 4 times 2 h between 6 h and 22 h to repair failures results in even better milking quality indicators than when a maintenance service is continuously available between 6 h and 22 h and requires 1 h to reach the farm. Although the farmer will not always be able to solve the problems himself, the results indicate that *a training of the farmer in which he is taught the basics to repair common robot failures is a very worthwhile investment.*

Cows which fail automatic teatcup attachment require the assistance of the farmer. Instead of immediately assisting the cows when an attachment problem occurs, the system might separate these cows in a holding area. The farmer can then handle a group of separated cows at times appropriate to his labour planning and under his continuous supervision. Cows unsuitable for automatic teatcup attachment require additional work from the farmer. The farmer will have to set a maximum time that he wants to spend for this operation. When the farmer aims to spend a maximum of 0.5 h per group (three groups per day) for milking the separated cows, the herd may consist of 6 to 7% cows that are unsuitable for automatic attachment. Culling of these cows can be considered to reduce the labour input. If the cow is a high producing one, the decision may be hard to face. It is up to the farmer to set out the pros and cons before taking a decision. Failing teatcup attachment can also be caused by the system itself. We can derive that the milking robot has to achieve an attachment score of 93 to 94% to limit the additional work of the farmer to 1.5 h a day. This additional work consists mainly of supervision. Only 12 to 20% of the time is used for physical work (Sonck, 1995).

Considering the amount of labour for different AMS management strategies under unfavourable circumstances, it is obvious that unplanned milking operations lead to markedly lower labour savings for the AMS milking job. Therefore, high demands have to be set to AMS functioning and cow traffic to the AMS. The modelling approach presented in Chapter 5 and 6 is able to show the effects on labour requirement and labour organisation when these demands are not met.

5. Effects of automatic milking on the labour organisation at tactical level

The effects of the integration of an automatic milking system on the labour organisation of a dairy farm will depend on the characteristics of the farm at the moment of the introduction of the AMS and on the automatic milking management strategy applied once the AMS has been integrated in the farm. The introduction of an AMS may change the grazing system, the use of farmland, herd size (dairy cows and young stock), feeding strategy, etc. The choice of these 'transition variables' will determine the farmer's new management style and consequently the labour requirement and labour organisation at tactical level. The grazing system is an important decision factor. Grazing systems combined with automatic milking can be : unrestricted grazing with or without supplementary feeding of maize silage, restricted grazing with or without supplementary feeding of maize silage, zerograzing and summerfeeding. Fully automatic milking based on a 24 hours attendance of cows to the AMS supposes that cows are kept indoors and fed with roughage (grass or maize silage) the whole year, i.e. summerfeeding or fed with roughage in the winter and fresh cut grass in the summer, i.e. zerograzing. In case the operations for grass silage production with summerfeeding are executed by the farmer and his relatives, the labour savings obtained with automatic milking will mainly be absorbed by the surplus of work for producing grass silage. In our experiments we found labour savings of 816 h (15.7%) for a farming plan with only grassland (560 000 kg milk quota). Farms with grassland and maizeland will benefit more from the AMS since less labour savings of the milking job will be absorbed by work for grass silage production. In The Netherlands and Belgium work for maizeland is mainly done by contract workers. We found labour savings of 1312 h (20.0%) for a farm with grassland and maizeland. The application of summerfeeding with the AMS will result in four or five labour peaks during the summer period. These labour peaks will require hiring of contract workers, especially on small farms (up to 60 cows) where investment in machinery for grass silage production may not be economically justified. On medium large and large farms it can be considered to execute grass silage production with a surplus of labour input from the farmer and his relatives. Farmers using contract workers for grass silage production will benefit more from automatic milking in terms of labour reduction. For these farms, the labour reduction ranges from 923 h (20.0%) to 1371 h (29.6%) for farming plans with only grassland and 816 h (17.9%) to 1361 h (29.9%) for farming plans with grassland and maizeland. In this case summerfeeding appears to be the best alternative. Here, we conclude that for family farms with up to 80 cows, it could be attractive to combine automatic milking with summerfeeding as 'grazing system' and with employment of contract workers for the grass silage production.

Comparing various grazing systems for farming plans with grassland only we found in all cases a labour reduction of at least 15%, with a maximum of 22.2% (approx. 1150 h) for restricted grazing or overnight housing with supplementary feeding of 6 kg DM maize silage per day. For farming plans with grass- and maizeland the introduction of an AMS results in labour savings of 800 to 1000 h per year for all grazing systems.

From our results it appears that family farms with up to 80 cows will benefit the most of automatic milking in terms of labour reduction. Large farms will benefit from automatic milking if the AMS can fully replace the work of an employee . Depending on the number of cows, it might be necessary then to divide the herd in groups and to install more than one milking robot.

6. Prospects for the quality of life on robotic milking dairy farms

A higher quality of life can be achieved by a better work quality (lower mental and physical load), a more agreeable family and social life or an improved economic situation.

Studies on the labour requirement of robotic milking dairy farms have shown that automatic milking results in labour savings and consequently in a lower physical load of the milker. The automatic milking system relieves the farmer from the monotonous job of conventional milking (Seabrook, 1992). As physical work reduces, physical affections of the locomotive system will be reduced too with automatic milking (Hildebrandt, 1989; Lundqvist et al., 1993; Moilanen and Taattola, 1992). The mental load such as the time pressure and the required concentration of the milker with conventional milking disappears (Belt, 1984). The automated collection of cow related individual information will reduce the mental load of the farmer too.

The farmer will get a new milking job mainly consisting of monitoring tasks at the milking robot and in the cowshed. An unattended automatic milking system stands no chance to succeed. The farmer will have to control the milking process via a computer program delivered with the AMS. This means that the farmer needs to be familiar with working on a PC. In a first stage, he will have to learn to work with a general management program and if possible later with a 'problem solving program'. The latter means that the farmer is able to solve at least some of the problems at an AMS himself. It will make the farmer more familiar with the milking robot and its technical environment. In addition, it enables him to do quick interventions which are important for the continuation of the milking process. The AMS area will become a workplace with a lot of information and control devices. Not only ears and eyes, but also knowledge, will become an important factor for the work quality of automatic milking. The whole AMS and especially the management system must be clear, unambiguous and easy-to-use for a farmer, for example by its presentation and arrangement of information. These aspects can contribute to lower the mental load of the farmer. Of course, personal characteristics will always play an important role.

Lundqvist (1992) and Sonck (1992) pointed to the safety problems with milking robots. When the milker enters the robot-movement area accidents due to exposure to mechanical or electrical energy may occur. However, the speed of the robot and the forces executed by the robot arm (of the Prolion milking robot) are low.

The effects of automatic milking on the social life of the farmer and his family will depend on the AMS management strategy chosen by the farmer. With the AM-HCT method the farmer will still be tied to fixed milking times and he will still have to work at unsocial hours of the day. However, labour requirement is less than for conventional milking. The fully automatic milking method will free the farmer of milking during fixed periods and at unsocial hours of the day. It allows a more flexible labour planning. Living a more free social and family life comparable with that of other families will be possible. From this dissertation it may be clear that the system and the cows cannot be a day without human supervision. Automatic milking however allows a better tuning of the 'milking operations' and the daily labour planning. The state of being tied down to his farm will depend on the reliability of the system. Problems with cow traffic or technical problems will increase physical work load. Regular interventions to repair failures cause not only interruptions in the daily organisation (e.g. delay of operations) and family activities, but can also stress the farmer and disturb family life. A psychological approach of the farmer and his family by the milking robot company might be important to learn the reactions of the farmer and to succeed with the AMS. It is important to find to what extent the farmer is really able to work with the AMS and to accept and to deal with failures. The stress can increase when the farmer is unable to perform the repair himself. For this reason, a troubleshooting and repair training in which the farmer is taught to deal with routine system problems can be a valuable investment. In this context, clear job demarcation and procedures for troubleshooting and diagnosing failures have to be carefully outlined for example in the service manual.

An AMS represents a high investment which also contributes to the mental load on the farmer, especially if the farm is already into great debt. The break-even investment level for an AMS in comparison with a double eight herringbone milking parlour, is NLG 310 000 for The Netherlands (Harsh et al., 1992).

It is clear that automatic milking results in a reasonable labour saving. When this can be connected with the same or a better income for the farmer, the prospects for automatic milking are very promising.

7. Suggestions for further research

Most of the work described in this dissertation is based on labour data collected from dairy farms applying the AM-HCT method and on labour data from conventional milking dairy farms available at IMAG-DLO and RvL-CLO. At the time of starting our research no commercial dairy farms were available with a fully automatic milking method. In future, labour research is needed on robotic milking dairy farms applying the fully automatic milking method, e.g. time registration of all tasks during one year. Thereby, the effects of different grazing systems combined with automatic milking should be studied and compared with the results obtained from the labour budgeting program.

No data are available about the occurrence and the causes of machine downtimes. Collection of time series of failures with their specifications and their labour requirement for repair are needed. Although failure occurs mostly sudden, it is possible to analyze previous failures to assess the age dependence of the failure risk. It can be decided then whether a less frequent preventive replacement is justified. An analysis of these time series can contribute to a better mathematical description of failure occurrence and could be included in the current simulation model. It would enable more reliable calculations with regard to failures. As a consequence effects of failures on labour planning could be better approached. Furthermore, clarity is needed in the kind of technical problems that can be solved by the farmer himself and for which problems he needs to call a technician of the milking robot company. Training of the farmer has to be more than learning how to use an AMS.

Research as well as practical experience have learned that the success of automatic milking systems depends on the system and the cows. As a system can be changed, we have to adjust the system to the biological requirements of the cow (Humik, 1992). Cows have to be motivated to visit the AMS, in order to limit the farmer's involvement in the milking process. It appears that one-way traffic is the only way to guarantee enough visits of each cow to the AMS. Devir and Metz (1995) reported a voluntary attendance of 97% at the AMS with a herd of 24 cows milked 2 to 6 times per day. Field tests on one-way traffic are needed for herd sizes comparable with those on commercial farms, and a follow-up of commercial robotic milking dairy farms could also provide additional information. A higher number of cows might result in queueing of cows in front of the AMS. Long idle times may discourage cows from visiting the AMS and as a consequence may reduce the visits to the feeding area. Different forms of one-way traffic have to be investigated. Attention has to be paid to a swift walk-through between resting and feeding area. The integration of an efficient cow traffic system in different types of layout of cubicle houses needs to be evaluated.

In the appraisal of different farming plans with automatic milking, the study was restricted to a herd of 80 cows (560 000 kg milk quota). To evaluate the labour requirement, labour savings and labour organisation for farms with a smaller (60 cows) or larger (100 cows or more) herd size, new farming plans should be described and calculated using the labour budgeting program and additional modules for automatic milking.

To study the economic impact of the integration of automatic milking on a dairy farm, detailed economic calculations are needed. Until now, economic calculations with regard to automatic milking make no use of labour data or take only into account rough estimations of the labour savings (Armstrong et al., 1992; Harsh et al., 1992). The farming plans, labour budgets and results of the fodder supply made in the context of this dissertation can serve as a basis for more accurate economic calculations. Economic studies can learn us whether the most labour saving AMS management strategies are also financially the most attractive ones.

In the field of labour science, an analysis of the safety hazards for humans with automatic milking is required. This analysis could give advice on future AMS design. Farmers coping with such new technologies is another point to investigate. Therefore, labour psychologists should be involved to study how automation influences the quality of working life. In this context, it may be worthwhile to study the performances of top farmers to learn how they deal with problems.

8. Final conclusions

- With a simple formula of tuning for robot and cow cycle duration it is possible to show that the capacity of current automatic milking systems can be improved by changing the sequence of certain activities and by programming the simultaneous execution of activities, like opening the entrance doors of the milking stall and the milking parlour. These adjustments result in shorter idle times for the cows and the robot arm and consequently in shorter milking times.
- Automatic milking with human-controlled cow traffic is a suitable way of milking. In comparison to conventional milking AM-HCT applied throughout the year and with a milking frequency of three times a day results in marked labour savings for the milking job (37.9%). The AM-HCT method can only be applied on farms with a small herd size (< 50 cows) if only two milking stalls are available. Application of the AM-HCT method on larger farms, requires an extension of the AMS with milking stalls and eventually with a (rotary) robot arm. Therefore, the installation of a milking robot in

conventional milking parlours may provide an economically attractive solution for this capacity problem.

- Automatic milking with computer-controlled cow traffic merely requires starting-up procedures, cleaning tasks and a regular inspection during the day. The AM-CCT method results in a labour reduction of 66.1% for the milking job in comparison to conventional milking. Unexpected failures or repairs were not included in these calculations.
- The AMS management strategy will determine the absolute and relative importance of the labour requirement for planned and unplanned milking operations. With regard to the amount of labour for the different AMS management strategies under unfavourable circumstances, unplanned milking operations lead to marked reductions in labour savings with the AMS. Therefore, high demands have to be set to AMS functioning and to cow traffic to the AMS.
- A permanently available maintenance service is very important to assure the quality of the milking process, especially on those farms where the AMS already operates at the limit of its capacity. The results indicate that a training of the farmer in which he is taught the basics to repair small robot failures is a worthwhile investment.
- For labour organisation at tactical level when using an AMS, we stress that the labour requirement and labour savings will largely depend on the decisions taken by the farmer with respect to the use of contract work, the use of the available farmland and on the milk quota. In all experiments, the labour budget of a robotic milking dairy farm results in labour savings when compared to conventional milking dairy farms. We found labour savings of minimum 1.8% (91 h) for a farming plan with only grassland, summerfeeding and a herd of 80 cows and labour savings of maximum 29.9% (1361 h) for a farming plan with grassland and maizeland, summerfeeding, a herd of 70 cows and with contract work for grass and maize silage production.
- Family farms with up to 80 cows will benefit most of fully automatic milking in terms of labour reduction, especially when summerfeeding is applied and contract workers are hired for grass silage production. It will result in a low labour input throughout the year (slight labour peaks). Other grazing systems will result in more work for the milking job and lower labour savings. When fully automatic milking is applied on large farms, the herd will have to be divided into small groups (40 to 80 cows). Summerfeeding can then be applied with or without the employment of contract workers for grass silage production. The size of the farmland will here determine which solution will be the most economical one. If one wants to apply a grazing system in which cows are pasturing, the AMS will need to have a high capacity in order to apply automatic milking with a human-controlled cow traffic. The grazing system of the conventional milking dairy farm can be continued.
- Automatic milking will contribute to a lower physical and mental load of the farmer and his relatives if problems with cow traffic and technical problems can be kept to a minimum. The farmer will become more an intellectual worker than a manual labourer. More time will be available for animal care and farm management in general. Automatic milking can improve the farmer's social and family life. For certain persons automatic milking might lead to task enlargement and task enrichment, for others however, it might lead to stress situations. Therefore, a labour psychological

study to investigate objectively the negative and positive psychological consequences of the robotization for the (potential) robotic milking dairy farmers and their family is recommended.

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Labour organisation on robotic milking dairy farms

Summary

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1. Research issues
2. The milking capacity of a milking robot
3. Labour organisation at operational level
4. Labour organisation at tactical level
5. Final conclusions

1. Research issues

The research described in this dissertation is focused on the effects of the integration of the milking robot in a dairy farm on the labour organisation at operational and tactical level. Attention was paid to the future requirements concerning human labour and labour (re)organisation with respect to the complex interaction between the cows and an automatic milking system (AMS) on a robotic milking dairy farm. The study was divided in a number of research issues (Chapter 1) :

(a) What is the capacity of a milking robot ? In determining the amount of human labour that can be replaced by the milking robot, the capacity of the milking robot forms an indispensable basis for calculations of possible labour requirement when an AMS is used.

(b) What are the remaining "milking" operations and work elements of the farmer according to the chosen work method with the AMS ? Because cows will be kept closer to the milking system, other grazing systems than unrestricted grazing where cows are pasturing day and night will have to be applied with automatic milking. Therefore, the question requires an evaluation of the work methods with an AMS and grazing systems. A grazing system refers here to a specific time distribution of "keeping cows in- or outdoors" on daily and yearly basis.

(c) What are the effects of different AMS management strategies on the daily labour requirement and labour organisation at operational level ?

(d) What are the effects of different AMS management strategies on the annual labour requirement and the labour organisation at tactical level ? What are the possible annual labour savings in comparison with conventional milking dairy farms ?

(e) The results of the above-mentioned research questions will have to give indications about labour quality and the quality of life of the farmer on robotic milking dairy farms.

The two main AMS management strategies considered in the dissertation are : (1) the fully-automatic strategy with computer-controlled cow traffic based on voluntary visits of the cows to the milking point during 24 h of the day, a cubicle house with restricted one-way cow traffic and individual concentrate supplementation and milking (AM-CCT) and (2) a semi-automatic strategy with human-controlled cow traffic based on milkings at fixed moments of the day, under supervision of the farmer and either individual concentrate supplementation by means of computerized self-feeders or group feeding using a total mixed ration (AM-HCT). All studies discussed in this dissertation used an automatic milking system with a 'Prolion' milking robot with one robot arm serving one or more milking stalls. From an evaluation of the dairy technology, we conclude that technical solutions for the automation of each milking operation performed in conventional milking parlours are potentially available (Chapter 2). Automatic milking can replace the milker and the milking parlour to a large extent.

2. The milking capacity of a milking robot

The interaction between milking robot and cow was investigated by means of a simple formula of tuning which enables to calculate the milking capacity of any type of milking robot (Chapter 3 or research issue (a)). Using this static model, the main factors of robotic milking such as the times required for cow movements, milking processes and robot motions were investigated. It was shown that for a milking robot with one robot arm serving two stalls, the idle time of the robot arm was 54% and that the robot arm can serve up to four milking stalls in-line. The model showed also that the capacity of an AMS arrangement with two stalls in-line, can be increased from 11.7 to nearly 15.4 cows/h by increasing the robot speed, by simultaneous executing of some milking processes such as the simultaneous opening of the entrance doors of the milking stall and the milking parlour, and by changing the sequence of milking processes. If the robot is available for milking for 20 h, 308 milkings could theoretically be carried out. Thus, with a milking frequency of four milkings per cow per 24 h for the whole herd, the milking robot could serve nearly 80 cows.

With the same modelling approach, formulae were developed to assess and evaluate fictitious AMS arrangements and to estimate capacities. A double or rotary tandem AMS arrangement can be a good alternative for an AMS with four or five milking stalls in-line. In a 2 x 2 tandem arrangement the capacity (cows/h) would be 8.5% higher than in a one-row arrangement. Cycle analysis showed that with a rotary tandem comprising five milking stalls a capacity of 29 cows/h can be reached. Arrangements with more than five milking stalls do not improve capacity, if the speed of the robot processes cannot be increased. If these processes could be carried out faster six milking stalls could be used and a capacity of nearly 39 cows/h could be reached.

3. Labour organisation at operational level

In general the farmer can allocate his time to milking job, non-milking jobs, personal care and social activities. Two kinds of operations can be distinguished in the milking job using automatic milking viz. planned and unplanned milking operations.

Times for planned milking operations were derived from observations on commercial farms where automatic milking was combined with a human-controlled cow traffic and on an experimental farm where automatic milking was combined with computer-controlled cow traffic (Chapter 4 or research issue (b)). Based on these work studies, the 'planned' milking operations of the milking job were derived for automatic milking methods combined with five grassland strategies. Seventeen variants were quantified by means of a case-study. Calculations with a developed task time program show that the automatic milking method with human-controlled cow traffic applied during the whole year and with a milking frequency of three times a day results in important physical labour savings for milking (37.9%). This method allows to apply grazing systems where cows are pasturing even day and night. However, automatic milking with computer-controlled cow traffic with cows kept indoors the whole year results in the largest labour reduction (66.1%).

The unplanned milking operations include (1) repair of robot failures, (2) bringing cows that exceed a maximum milking interval to the milking point and (3) interventions for cows which fail automatic teatcup atttachment. Malfunctioning of the AMS will determine the occurrence of unplanned milking operations which can disturb the daily labour planning. On the other hand, the daily planned tasks during which the farmer cannot be disturbed and is unavailable to the AMS, will delay unplanned milking operations and therefore negatively affect AMS functioning. To study the interdependency of automatic milking and labour planning at operational level, a dynamic stochastic simulation model (Chapter 5) and a program for labour planning quality (Chapter 6) were developed. For bringing cows to the AMS, it was found that bringing cows during three fixed periods to the AMS is preferable with respect to the low labour requirement, the low impact on labour planning and the negligible negative effect on the average milking interval and the milk production. The farmer will have to learn how the cows behave in the cubicle house and depending on their visiting pattern and production level he has to choose the maximum allowable milking interval. The choice of the maximum milking interval has a marked influence on the number of cows that need to be brought to the AMS and consequently, on the labour requirement of this operation.

One of the most important concerns of potential robotic milking dairy farmers is how to deal with robot failures. Robot failures and repair are defined as unplanned milking operations. The simulation model described in Chapter 5 makes it possible to study the effects of robot failures on the quality of the milking process for different degrees of availability of the farmer or the maintenance service to the system. The results show that a permanently available maintenance service is very important to guarantee the quality of the milking process, especially on those farms where the AMS already operates at the limit of its capacity. We learned that the milking process will benefit more from a farmer who is able to repair most of the robot failures himself and without delay than from one who always immediately calls in the maintenance service of the robot manufacturer.

Cows unsuitable for automatic teatcup attachment require additional work from the farmer. The farmer will have to set a maximum time that he wants to spend for this operation. When the farmer aims to spend a maximum of 0.5 h per group (three groups per day) for milking the separated cows, the herd may consist of 6 to 7% cows that are unsuitable for automatic attachment. Culling of these cows can be considered to reduce the labour input. If the cow is a high producing one, the decision may be hard. It is up to the farmer to set out the pros and cons before taking a decision. Failing teatcup attachment can also be caused by the system itself. We can derive that the milking robot has to achieve an attachment score of 93 to 94% to limit the additional work of the farmer to 1.5 h a day. This additional work consists mainly of supervision. Only 12 to 20% of the time is used for physical work.

4. Labour organisation at tactical level

The effects of the integration of an automatic milking system on the labour organisation of a dairy farm at tactical level will depend on the characteristics of the farm at the moment of the introduction of the AMS and on the automatic milking management strategy applied once the AMS is integrated in the farm. By combining two existing programs, namely the IMAG-ARBGRO labour budgeting program, extended with task time modules for automatic milking and the program 'Standards for Fodder Supply', it was possible to calculate the labour budget of robotic milking dairy farms with various grazing systems applied and to compare these farms with conventional milking dairy farms (Chapter 7). In several experiments we studied the following grazing systems combined with automatic milking : unrestricted grazing with or without supplementary feeding of maize silage, restricted grazing with or without supplementary feeding of maize silage, zerograzing (cows indoors the whole year and feeding fresh cut grass) and summerfeeding (cows indoors the whole year and feeding grass or maize silage). Fully automatic milking based on a 24 hours attendance of cows to the AMS supposes summerfeeding or zerograzing.

Comparing various grazing systems for farming plans with grassland only we found that all cases result in a labour reduction of at least 15%, with a maximum of 22.2% (approx. 1150 h) for restricted grazing or overnight housing with supplementary feeding of 6 kg DM maize silage per day. For farming plans with grass- and maizeland the introduction of an AMS results in labour savings of 800 to 1000 h per year for all grazing systems compared. Farmers using contract workers for grass silage production will profit more from automatic milking in terms of labour reduction. For these farms, the labour reduction ranges from 923 h (20.0%) to 1371 h (29.6%) for farming plans with only grassland and 816 h (17.9%) to 1361 h (29.9%) for farming plans with grassland and maizeland. If we compare different grazing systems for this case, summerfeeding appears to be the best alternative.

From the discussion in Chapter 8, we summarize that automatic milking is a working tool for the farmer that will lighten the mental and physical load and as such will lead to a higher work quality. The farmer will need to become acquainted with this technically and electronically sophisticated device. The farmer will become more a brain worker than a manual labourer. The effects of automatic milking on his family and social life will depend on the AMS management strategy chosen by the farmer. Some cases where automatic milking may lead to a higher stress are discussed. In this context, labour psychological studies are needed to learn how the farmer and his family deal with stress situations and how they solve the related problems.

5. Final conclusions

- With a simple formula for tuning for robot and cow cycle duration it is possible to show that the capacity of current automatic milking systems can be improved by changing the sequence of certain activities and by programming the simultaneous execution of activities, like the simultaneous opening of the entrance doors of the milking stall and the milking parlour. These adjustments result in shorter idle times for the cows and the robot arm and consequently in shorter milking times.
- Automatic milking with human-controlled cow traffic is a suitable way of milking. In comparison to conventional milking AM-HCT applied throughout the year and with a milking frequency of three times a day results in marked labour savings for the milking job (37.9%). The AM-HCT method can only be applied on farms with a small herd size (< 50 cows) if only two milking stalls are available. Application of the AM-HCT method on larger farms, requires an extension of the AMS with milking stalls and eventually with a (rotary) robot arm. Therefore, the installation of a milking robot in conventional milking parlours may provide an economically attractive solution for this capacity problem.

- Automatic milking with computer-controlled cow traffic merely requires starting-up procedures, cleaning tasks and a regular inspection during the day. The AM-CCT method results in a labour reduction of 66.1% for the milking job in comparison to conventional milking. Unexpected failures or repairs were not included in these calculations.
- The AMS management strategy will determine the absolute and relative importance of the labour requirement for planned and unplanned milking operations. With regard to the amount of labour for the different AMS management strategies under unfavourable circumstances, unplanned milking operations lead to marked reductions in labour savings with the AMS. Therefore, high demands have to be set to AMS functioning and to cow traffic to the AMS.
- A permanently available maintenance service is very important to assure the quality of the milking process, especially on those farms where the AMS already operates at the limit of its capacity. The results indicate that a training of the farmer in which he is taught the basics to repair small robot failures is a worthwhile investment.
- For labour organisation at tactical level when using an AMS, we stress that the labour requirement and labour savings will largely depend on the decisions taken by the farmer with respect to the use of contract work, the use of the available farmland and on the milk quota. In all experiments, the labour budget of a robotic milking dairy farm results in labour savings when compared to conventional milking dairy farms. We found labour savings of minimum 1.8% (91 h) for a farming plan with only grassland, summerfeeding and a herd of 80 cows and labour savings of maximum 29.9% (1361 h) for a farming plan with grassland and maizeland, summerfeeding, a herd of 70 cows and with contract work for grass and maize silage production.
- Family farms with up to 80 cows will benefit most of fully automatic milking in terms of labour reduction, especially when summerfeeding is applied and contract workers are hired for grass silage production. It will result in a low labour input throughout the year (slight labour peaks). Other grazing systems will result in more work for the milking job and lower labour savings. When fully automatic milking is applied on large farms, the herd will have to be divided into small groups (40 to 80 cows). Summerfeeding can then be applied with or without the employment of contract workers for grass silage production. The size of the farmland will here determine which solution will be the most economical one. If one wants to apply a grazing system in which cows are pasturing, the AMS will need to have a high capacity in order to apply automatic milking with a human-controlled cow traffic. The grazing system of the conventional milking dairy farm can be continued.
- Automatic milking will contribute to a lower physical and mental load of the farmer and his relatives if problems with cow traffic and technical problems can be kept to a minimum. The farmer will become more an intellectual worker than a manual labourer. More time will be available for animal care and farm management in general. Automatic milking can improve the farmer's social and family life. For certain persons automatic milking might lead to task enlargement and task enrichment, for others however, it might lead to stress situations. Therefore, a labour psychological study to investigate objectively the negative and positive psychological consequences of the robotization for the (potential) robotic milking dairy farmers and their family is recommended.

Arbeidsorganisatie op melkveebedrijven met een melkrobot

Samenvatting

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1. Doelstellingen
2. De capaciteit van een melkrobot
3. Arbeidsorganisatie op operationeel niveau
4. Arbeidsorganisatie op tactisch niveau
5. Belangrijkste besluiten

computer-gestuurd koeverkeer waarbij de koeien het ganse jaar in de stal worden gehuisvest resulteert in de grootste arbeidsbesparing (66,1%).

De ongeplande handelingen van het melken omvatten (1) herstellingen van robotfouten of -storingen, (2) opdrijven van koeien die een maximum melkinterval overschrijden naar de melkrobot toe en (3) interventies bij het falen van het automatisch aanzetten van de tepelbekers. De mate van optreden van deze ongeplande handelingen wordt bepaald door het wel of niet goed functioneren van het automatisch melksysteem. De ongeplande melkhandelingen zullen de dagelijkse arbeidsplanning verstoren. De dagelijkse geplande taken op het bedrijf waarbij de veehouder niet kan gestoord worden en dus onbeschikbaar is voor het AMS, zullen het tijdstip van uitvoering van ongeplande melkhandelingen doen verschuiven in de tijd en bijgevolg een negatief effect hebben op het automatisch melken. Om de onderlinge afhankelijkheid van het automatisch melken en de arbeidsplanning op operationeel niveau te bestuderen, werd een dynamisch stochastisch model (Hoofdstuk 5) en een programma voor de arbeidsplanning-kwaliteit (Hoofdstuk 6) ontwikkeld. Zo werd voor de onderzochte gevalstudies gevonden dat het ophalen van koeien die zich niet tijdig aan het AMS presenteren bij voorkeur gedurende drie vaste perioden van de dag gebeurt, dit omwille van de lage arbeidsbehoefte, de relatief lage impact op de arbeidsplanning en het verwaarloosbaar negatief effect op het gemiddelde melkinterval en melkproductie. De veehouder zal moeten leren hoe zijn koeien zich gedragen in zijn ligboxenstal en afhankelijk van hun AMS-bezoekpatroon en hun productie-niveau zal hij het toelaatbare maximum melkinterval moeten instellen. De keuze van het maximum melkinterval heeft een duidelijke invloed op het aantal koeien welke opgehaald moeten worden en bijgevolg op de arbeidsbehoefte voor deze handeling.

Eén van de meest voorkomende zorgen van potentiële gebruikers van een melkrobot is de vraag hoe om te gaan met robotstoringen. Robotstoringen en herstellingen zijn gedefinieerd als ongeplande melkhandelingen. Het simulatiemodel beschreven in Hoofdstuk 5 laat toe de effecten van robotstoringen op de kwaliteit van het melkproces te bestuderen voor verschillende mogelijkheden van beschikbaarheid van de veehouder of de onderhoudsdiensten voor het systeem.

De resultaten tonen aan dat het heel belangrijk is permanent beroep te kunnen doen op een onderhoudsdienst om de kwaliteit van het melkproces te garanderen, vooral op deze bedrijven waar het AMS reeds werkt op de limiet van zijn capaciteit. Uit simulaties is af te leiden dat de kwaliteitsindicatoren van het melkproces beter zijn ingeval de veehouder zelf en zonder enige vertraging de meeste robotstoringen kan oplossen dan wanneer hij telkens de hulp moet inroepen van de onderhoudsdiensten van de melkrobotfabrikant.

Koeien die door de robot niet kunnen worden aangesloten (bv. een afwijkende uiervorm) worden gesepareerd en nadien onder begeleiding van de veehouder gemolken. Een veehouder zal in dit geval eisen gaan stellen aan de hoeveelheid tijd die hij aan dit werk wil spenderen. Als de veehouder maximum 0,5 uur per groep (en drie groepen per dag) wil spenderen om de gesepareerde dieren te melken, dan mag de veestapel slechts uit 6 tot 7% koeien bestaan welke niet door de robot kunnen worden aangesloten. Het uitstoten van deze dieren kan overwogen worden om deze bijkomende arbeid uit te schakelen. Als het een hoog productief dier betreft, zal deze keuze hoedanook moeilijk zijn. Het is aan de veehouder om de voor- en nadelen van deze beslissing af te wegen. Het falen van de tepelbekeraansluiting kan echter ook veroorzaakt worden door het slecht functioneren van het robotsysteem. Uit het bovenstaande kunnen we afleiden dat de melkrobot een succesrijk aansluitpercentage moet hebben van 93 tot 94% om het bijkomend werk voor het melken van gesepareerde koeien te beperken tot 1,5 uur per dag. Dit bijkomend werk vergt in hoofdzaak controle van het melkproces door de veehouder. Slechts 12 tot 20% van deze melktijd wordt er fysieke arbeid geleverd.

4. Arbeidsorganisatie op tactisch niveau

De effecten van integratie van een automatisch melksysteem in een melkveebedrijf op de arbeidsorganisatie op tactisch niveau is afhankelijk van de karakteristieken van het bedrijf op het moment van de introductie van het AMS en van de AMS management strategie. Door combinatie van twee bestaande programma's, namelijk het IMAG-ARBGRO arbeidsbegrotingsprogramma uitgebreid met taaktijdmodules voor automatisch melken en het programma 'Normen voor Voedervoorziening', was het mogelijk de arbeidsbegroting van melkveebedrijven met een automatisch melksysteem en met verschillende begrazingssystemen te berekenen en te vergelijken met melkveebedrijven waar conventioneel wordt gemolken (Hoofdstuk 7). Verschillende begrazingssystemen gecombineerd met automatisch melken werden bestudeerd : onbeperkt grazen met of zonder bijvoedering van snijmaïs, beperkt grazen met of zonder bijvoedering van snijmaïs, zomerstalvoedering (koeien blijven het ganse jaar binnen en worden tijdens de zomer in de stal gevoederd met vers gemaaid gras) en summerfeeding (koeien blijven het ganse jaar binnen en worden in de zomer in de stal gevoederd met graskuil of snijmaïs). Volautomatisch melken met vrijwillige presentatie van de koeien aan de robot gedurende 24 u per dag veronderstelt de toepassing van zomerstalvoedering of summerfeeding.

In de vergelijking van verschillende begrazingssystemen voor bedrijfsplannen met enkel grasland, vonden we voor alle gevallen een arbeidssbesparing van ten minste 15%, met een maximum van 22,2% (ongeveer 1150 uren) voor beperkt grazen of enkel 's nachts opstallen met bijvoedering van 6 kg DS snijmaïs per dag. Voor bedrijfsplannen met gras- en maïsland resulteert de introductie van een AMS in arbeidsbesparingen van 800 tot 1000 uren per jaar voor alle in de studie opgenomen begrazingssystemen. Melkveehouders welke beroep doen op loonwerk voor de graskuilproductie zullen meer voordeel halen uit het automatisch melken in termen van arbeidsreductie. Voor deze laatste bedrijven bedraagt de arbeidsreductie 923 uren (20,0%) tot 1371 uren (29,6%) voor bedrijfsplannen met enkel grasland en 816 uren (17,9%) tot 1361 uren (29,9%) voor bedrijfsplannen met gras- en maïsland. Als we de verschillende begrazingssystemen in deze gevallen vergelijken dan blijkt summerfeeding het beste alternatief te zijn.

Van de discussie in Hoofdstuk 8 wordt het volgende samengevat. Het automatisch melksysteem is een werkmiddel voor de veehouder dat de mentale en fysieke belasting verlicht en zo de *arbeidskwaliteit verhoogt. De veehouder zal moeten leren omgaan met deze technisch en* electronisch gesofistikeerde installatie. In vergelijking met conventioneel melken, zal de veehouder meer hoofdarbeid verrichten dan handarbeid. De effecten van het automatisch melken voor het familiaal en sociaal leven zullen afhankelijk zijn van de door de veehouder gekozen AMS management strategie. Enkele gevallen waar het automatisch melken kan leiden tot stress-situaties, zijn vermeld. Arbeidspsychologisch onderzoek is noodzakelijk om beter inzicht te krijgen in hoe de veehouder en zijn gezin omgaan met stress-situaties rond het automatisch melken en hoe zij de problemen oplossen.

5. Belangrijkste besluiten

- Met een eenvoudige evenwichtsformule waarin de cyclusduur van de robot en de koe is opgenomen is het mogelijk aan te tonen dat de capaciteit van de huidige automatische melksystemen kunnen verhoogd worden door o.a. de volgorde van bepaalde processen te wijzigen of door de simultane uitvoering van processen, zoals het simultaan openen van ingangsdeuren van melkstal en melkstand. Dergelijke aanpassingen resulteren in kortere wachttijden voor koeien en robotarm en bijgevolg in kortere melktijden.
- Automatisch melken met een mens-gestuurd koeverkeer is een in de praktijk toepasbare methode van melken. In vergelijking met conventioneel melken resulteert een AM-MKV methode die het ganse jaar wordt toegepast met een melkfrequentie van driemaal daags in een opmerkelijke arbeidsbesparing van de melktaak (37,9%). De AM-MKV methode met een AMS bestaande uit 2 melkstanden kan enkel op bedrijven met een kleinere veestapel (< 50 koeien) worden toegepast. Toepassing van de AM-MKV methode op grote bedrijven vereist een uitbreiding van het AMS met meerdere melkstanden en eventueel met een (draaibare) robotarm. De installatie van een melkrobot in conventionele melkstallen zou daarom weleens een economisch attractieve oplossing kunnen bieden voor dit capaciteitsprobleem.
- Automatisch melken met computer-gestuurd koeverkeer vergt van de veehouder nog begeleiding bij de opstartprocedures, reinigingstaken en regelmatige inspectie gedurende de dag. De AM-CKV methode resulteert in een arbeidsreductie van 66,1% voor de melktaak in vergelijking met conventioneel melken. Storingen of herstellingen aan de robot zijn niet opgenomen in deze berekeningen.
- De AMS management strategie zal het absoluut en relatief belang van de arbeidsbehoefte voor geplande en ongeplande melkhandelingen bepalen. Met betrekking tot de hoeveelheid arbeid nodig bij verschillende AMS management strategieën beschouwd onder ongunstige omstandigheden, kunnen ongeplande melkhandelingen de arbeidsbesparing met automatisch melken sterk reduceren. Daarom moeten hoge eisen worden gesteld aan het betrouwbaar functioneren van het AMS en aan het koeverkeer rond het AMS.
- Een permanent beschikbare onderhoudsdienst is zeer belangrijk ten einde de kwaliteit van het melkproces te verzekeren, in het bijzonder op deze bedrijven waar het AMS opereert op de rand van zijn capaciteit. De resultaten geven aan dat een opleiding van de veehouder waarin hem de basistechnieken geleerd worden om zelf kleine reparaties uit te voeren een waardevolle investering is.

- Voor wat betreft de arbeidsorganisatie op tactisch niveau bij automatisch melken besluiten we dat de arbeidsbehoefte en arbeidsbesparingen grotendeels afhankelijk zijn van de beslissingen van de veehouder omtrent de inzet van loonwerk, het gebruik van de bedrijfsoppervlakte en de melkquota. In alle experimenten resulteerde de arbeidsbegroting van de melkveebedrijven met een melkrobot in arbeidsbesparingen in vergelijking met bedrijven die conventioneel melken. We vonden arbeidsbesparingen van minimum 1,8% (91 uren) voor een bedrijfsplan met enkel grasland, summerfeeding en een veestapel van 80 koeien en van maximum 29,9% (1361 uren) voor een bedrijfsplan met gras- en maïsland, summerfeeding, een veestapel van 70 koeien en met loonwerk voor de graskuil- en snijmaïsproductie.
- Gezinsbedrijven met een veestapel tot 80 koeien zullen het meeste nut hebben aan volautomatisch melken in termen van arbeidsbesparing, vooral als summerfeeding wordt toegepast en loonwerkers worden ingezet voor de graskuilproductie. Dit resulteert in een lage arbeidsbehoefte gedurende het ganse jaar (weinig of geen arbeidspieken). Andere begrazingssystemen resulteren in meer werk voor de melktaak en dus in lagere arbeidsbesparingen. Als volautomatisch melken wordt toegepast op grotere bedrijven, zal de veestapel in kleinere groepen (40 tot 80 koeien) moeten opgesplitst worden. Summerfeeding kan dan met of zonder de inzet van loonwerk voor de graskuilproductie toegepast worden. De grootte van de bedrijfsoppervlakte en de percelen zal ondermeer bepalen welke oplossing de meest economische is. Als men een begrazingssysteem wenst toe te passen waarbij de koeien weiden, zal het AMS een hogere capaciteit moeten hebben om volgens de AM-MKV methode te kunnen melken. Het begrazingssysteem van het conventioneel melkende bedrijf kan dan worden gecontinueerd.
- Automatisch melken zal bijdragen tot een lagere fysieke en mentale belasting van de veehouder en zijn gezin als de problemen met het koeverkeer en technische problemen tot een minimum kunnen worden gehouden. De veehouder zal meer hoofdarbeid dan handenarbeid verrichten in vergelijking met voorheen. Er zal meer tijd beschikbaar komen voor het verzorgen van de dieren en het bedrijfsmanagement in het algemeen. Automatisch melken kan het sociaal en familiaal leven van de veehouder ten goede komen. Voor bepaalde personen zal automatisch melken leiden tot een taakverruiming en -verrijking, voor anderen echter kan het stress-situaties veroorzaken. Daarom is een arbeidspsychologisch onderzoek naar de negatieve en positieve psychologische gevolgen voor (potentiële) gebruikers van een melkrobot en voor hun gezin noodzakelijk.

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Curriculum vitae

Bart Sonck, zoon van Annie Fermon en Wilfried Sonck, werd geboren op 2 augustus 1965, te Ninove, België. Hij is gehuwd met Inge Goessens en heeft twee kinderen : Laurien en Siem. Hij volgde het basis- en middelbaar onderwijs in het Sint-Aloysiuscollege te Ninove, alwaar hij in 1983 het diploma Wetenschappelijke A (Wiskunde) en de prijs Wiskunde behaalde. In hetzelfde jaar begon hij zijn studies aan de Faculteit Toegepaste Landbouwkundige en Biologische Wetenschappen van de Universiteit van Gent en studeerde daar af in 1988 als Landbouwkundig Ingenieur met specialisatie Boerderijbouwkunde - mechanica-constructies. Gedurende zijn legerdienst van februari 1989 tot januari 1990 volgde hij aan de hogeschool BME Gent een cursus Marketing en commerciële organisatie. Sinds 1 februari 1990 tot op heden werkt hij als 'research assistant' op het Rijksstation voor Landbouwtechniek, Merelbeke, België, dat ressorteert onder het Centrum voor Landbouwkundig Onderzoek - Gent, Ministerie van Middenstand en Landbouw, waar hij onderzoek verricht op het gebied van huisvesting van dieren, diergedragingen en dierenwelzijn in relatie tot hun huisvesting en management in de veehouderij. In 1994 won hij de Prof. Armand Blanc prijs voor jonge onderzoekers op het XII CIGR World Congress te Milaan voor een presentatie over de methodologie voor het maken van arbeidsstudies in de landbouw. Van 1992 tot 1995 werkte hij tevens als gastmedewerker op de afdeling Bedrijfsmanagement van het DLO - Instituut voor Milieu en Agrotechniek, IMAG-DLO, Wageningen, Nederland om er het onderzoek uit te voeren welke geleid heeft tot dit proefschrift.

Bart Sonck was born to Annie Fermon and Wilfried Sonck on August 2, 1965 in Ninove, Belgium. He is married to Inge Goessens and is father of Laurien and Siem. He completed his primary and secondary education at Sint-Aloysius College in Ninove and received his diploma of Sciences (mathematics) and the price of Mathematics in 1983. In the same year, he started his studies at the Faculty of Applied Agricultural and Biological Sciences of the University of Ghent where he graduated in 1988 as Agricultural Engineer, specialisation Agricultural Buildings - Mechanics and Constructions. He served in the Belgian Army from February 1989 until January 1990. Meanwhile, he followed a course in Marketing and Commercial Organisation at the Technical University BME in Ghent. From February 1990 until now, he works as a research assistant at the Research Station of Agricultural Engineering at Merelbeke, Belgium, belonging to the Agricultural Research Centre - Ghent of the Ministry of Small Enterprises, Traders and Agriculture, where he carries out research in the field of animal housing, animal behaviour and welfare in relation to their housing, and management in animal husbandry. In 1994, he was awarded the Prof. Armand Blanc Prize for young researchers on the XIIth World Congress on Agricultural Engineering in Milan for a presentation on the methodology of work studies in agriculture. From 1992 until 1995, he also worked at the Department of Farm Management, DLO Institute of Agricultural and Environmental Engineering, IMAG-DLO, Wageningen, The Netherlands, as a scientific guest collaborator on the research that led to this dissertation.