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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 described 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, jobs are derived for automatic milking methods combined with five grassland strategies. 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 (38%). However, automatic milking with computer-controlled cow traffic results in a larger labour reduction (66%). The consequences of pasturing combined with automatic milking, on the labour requirement for milking are discussed.

Keywords: automatic milking, model, task time program, labour requirement

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 & 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 & Zegers, 1984; Belt, 1984; Stål & 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 strategy:

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 & 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 at-

tach 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 strategies can be applied :
   - unlimited grazing : cows remain in the pasture 24 h a day;
   - limited grazing : cows are during one long period of the day in the pasture (8 to 12 h);
   - limited grazing : cows are during one short period of the day in the pasture (4 h);
   - limited grazing : cows are during two short periods of the day in the pasture (2 × 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.

Materials and methods

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)(Figure 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 (Figure 1). From this point the milker supervised the milking process.

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 (Figure 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.

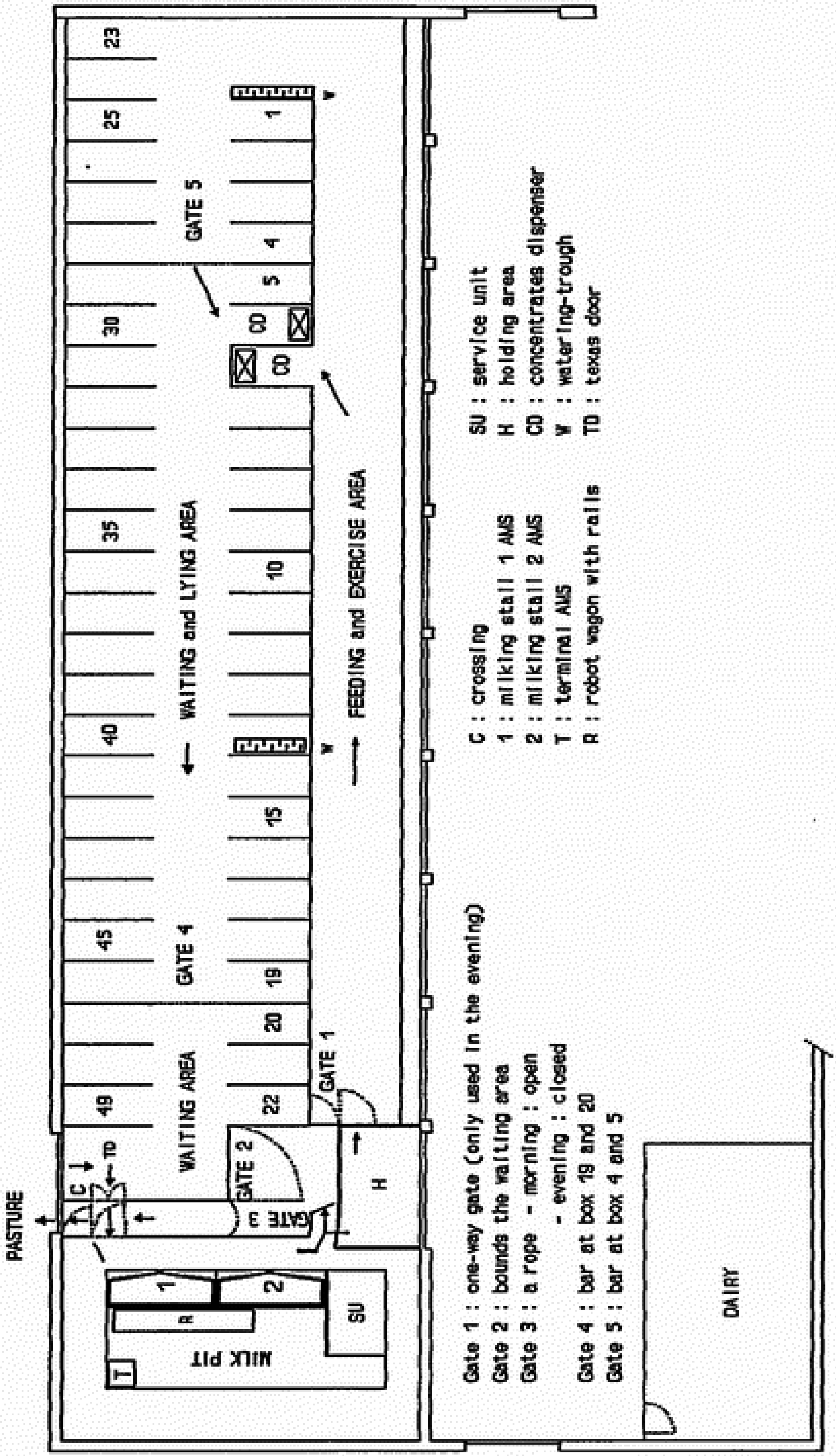

Figure 1. Layout of the cubicle loose house with automatic milking system.

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 & 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 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.

Results

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.

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. Figure 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

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.

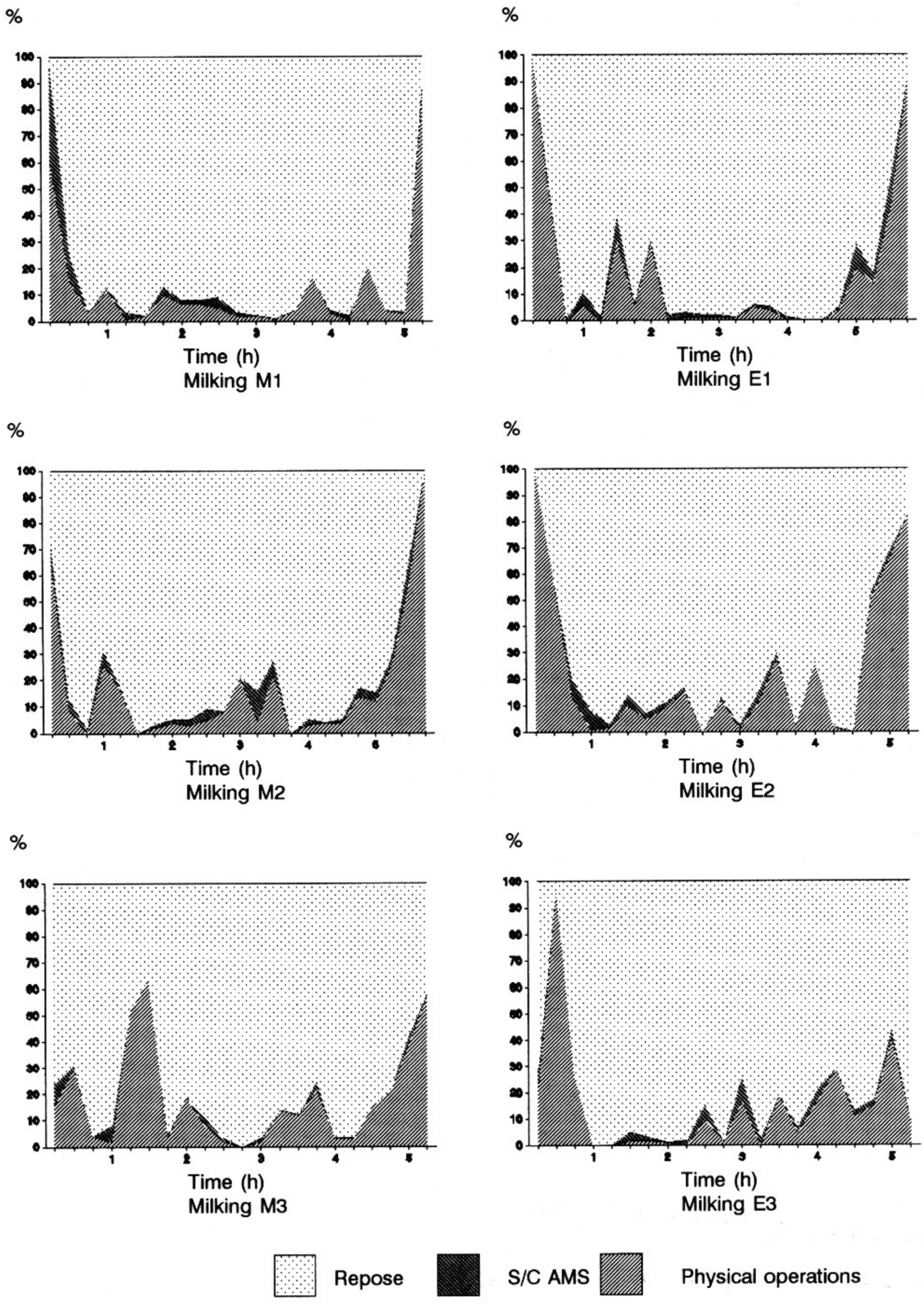

Figure 2. Proportional distribution of the operations (repose, service/control AMS and physical operations), during morning (at left) and evening (at right) milkings.

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.

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 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.

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 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:	milking 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	
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).

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,

Table 3. The basic times of 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).

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)

Table 5. Teatcup attachment results for each milking.

Milking	With robot (number)	(%)	With manual intervention (number)	(%)	Manual attachment (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

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 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% and 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.

- 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).

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

- 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).

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 Figure 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 : unlimited grazing (1), limited grazing during one long period (2), during one short period (3) and during two short periods per day (4). A fifth grassland strategy, 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

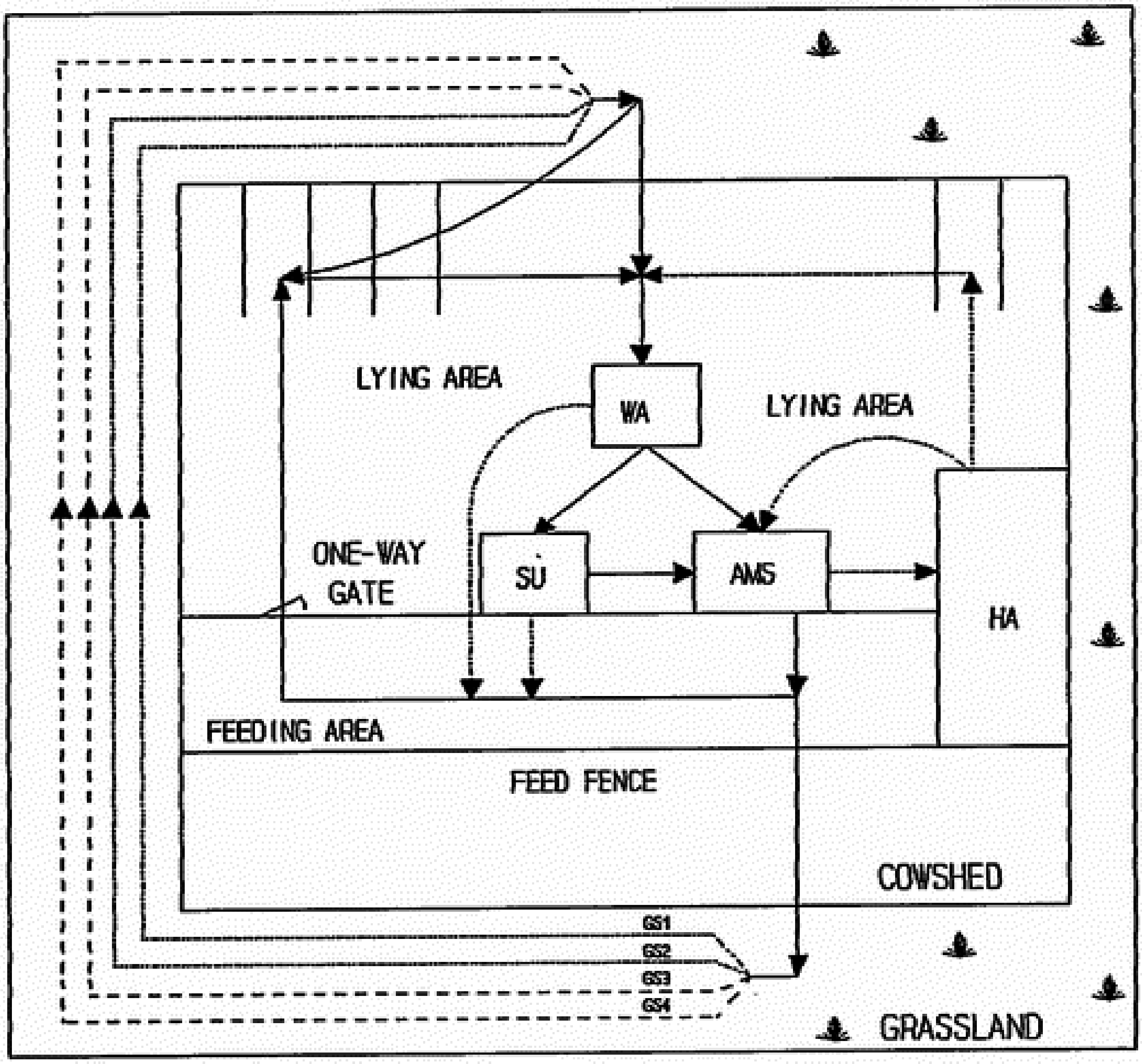

Figure 3. Visual model of the cow traffic with automatic milking in a total farm system, used as basis for a task-time program for automatic milking (AMS = automatic milking system; WA = waiting area; SU = selection unit; HA = holding area; GS 1 ... 4 = grassland strategies).

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 Figure 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.

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

where

- $LR_{AM\text{-}HCT}$ = 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.

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

where
$LR_{AM\text{-}CCT}$ = 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),

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

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

cs = cows stay in cowshed; zg = zerograzing; lg = limited grazing; ug = unlimited 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.

which are relevant to a 2 × 5 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 unlimited grazing, limited 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 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 (5 × 17 × 17) theoretical combinations available to the herdsman. Table 8 gives some examples of relevant combinations of milking methods and grazing strategies 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 intro-

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

Combination	Milking method and grazing strategy during			Physical labour requirement (h/year)	Relative physical labour requirement
	Winter period	Transition periods	Summer period		
1	HCT 2x cs	HCT 2x lg 1lp	HCT 2x ug	631.7	50.9
2	HCT 3x cs	HCT 3x lg 1lp	HCT 3x ug	944.0	76.0
3	HCT 2x cs	HCT 2x lg 1lp	HCT 2x lg 1lp	577.4	46.5
4	HCT 3x cs	HCT 3x lg 1lp	HCT 3x lg 1lp	834.5	67.2
5	HCT 3x cs	HCT 3x lg 1sp	HCT 3x lg 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 lg 1lp	HCT 2x ug	585.5	47.2
9	CCT 3x cs	HCT 3x lg 1lp	HCT 3x ug	771.0	62.1
10	CCT 3x cs	HCT 2x lg 1lp	HCT 2x lg 1lp	531.2	42.8
11	CCT 3x cs	HCT 3x lg 1lp	HCT 3x lg 1lp	661.5	53.3
12	CCT 3x cs	HCT 3x lg 1sp	HCT 3x lg 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 lg 1lp	CM 2x ug	1241.7	100.0
15	CM 2x cs	CM 2x lg 1lp	CM 2x lg 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; lg = limited grazing; ug = unlimited 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) duction 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 limited grazing during one long period of the day applied during the summer and transition periods, scores very well.

Discussion

According to Belt & 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 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 Tables 1 and 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 strategies 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 & 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 (pers. comm.) 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	11	10
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).