Demands and opportunities for operational management support

Operational management on farms with Automatic Milking Systems

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Information

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Operational management on farms with Automatic Milking Systems

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Abstract

It is generally recognised by now that with automatic milking operational farm management is considerably changed compared to conventional machine milking, and is a key issue to fulfil requirements in practise. An overall picture of changes in management when milking with an automatic milking system however is not available. Each manufacturer has different solutions for management support and performance of automatic tasks, and users can adapt various parameter settings to their own preferences. This report describes differences between conventional and automatic milking with respect to operational farm management. From these differences a list of demands for operational management with automatic milking systems is generated and compared with the possibilities of currently available systems. Opportunities and shortcomings are indicated and discussed.

A clear difference with conventional milking is that milking intervals have to be controlled for individual cows. Feeding strategy is a key element in this, especially when grazing is applied. Usually cows with too long intervals are fetched. With regard to health, in general much more indirect information is available, especially detection of mastitis partly depends on abnormalities detected with sensors. However, visual inspection of the animals remains an important method to control health. Because milkings are unattended, regularly abnormalities have to be checked. Because of the limited reliability of the alarms, and the fact that these are not yet integrated, this requires specific skills from the farmer. The automatic milking unit has to be maintained and its cleaning and functioning must be controlled more or less constantly. The cooling system has to be suited to automatic milking.

In order to be able to comply with legislation some of the currently existing regulation must be adapted, avoiding double standards. Farmers must have affinity with automation. They have to work with secure schedules, for instance first enter treatment data in the computer and then treat sic cows and respond as should on alarms for system and animals. Udders and teats must be kept clean. Farmers in general are satisfied with the current possibilities of AM systems and do not have a clear view which further improvements are possible. Despite this, not all of the demands for automatic milking are yet fulfilled by the current systems but this is also due to insufficient legislation. Especially automatic separation of abnormal milk and secured teat cleaning should be realised. Furthermore monitoring of the equipment can be improved. With these improvements automatic milking potentially has advantages with respect to milk quality and food safety compared to conventional milking.

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1 Introduction

Basic requirements with regard to automatic milking are determined both by animal physiology, milk quality, food safety and farmers demands. It is generally recognised by now that with automatic milking farm management is considerably changed compared to conventional machine milking, and is a key issue to fulfil requirements in practise. On the one hand physical labour is replaced by automation, but on the other hand additional tasks are introduced for farmers such as monitoring the automated process and maintenance of the automatic milking equipment. Cows are milked individually, preferably voluntarily and unattended, but farmers remain responsible for the overall farm operation, product quality and animal welfare. This implies that they should have access to information on the functioning of the equipment and especially are alarmed when action is required.

Automatic milking systems also need information in order to perform their tasks. Teats have to be localized before they can be cleaned and teat cups can be attached for instance. This information is obtained through sensors. Some actions or decisions are completely automated and purely based on information gathered by the system. It is unlikely however that all information used by the system for these decisions is relevant for the farmer. Most decision making however is not automated completely, but requires farmer's involvement. Relevant and reliable information is essential to be able to manage a dairy farm, especially for decision making. With conventional milking a lot of this information is obtained visually around and during milking, but this is impossible with automatic milking. Therefore automatic milking systems are equipped with features that collect large amounts of data and with software to transform this into information that could be useful for management support. Some of this information is purely meant to replace visual information, but also information is collected that can not be obtained visually, such as milk conductivity. Each manufacturer has different solutions for management support and performance of automatic tasks, and users can adapt various settings to their own preferences. Dairy farmers working with the different systems have practical experience in handling the information to support managing their herds. Besides this, the work packages 1-10 of the European research project QLK5-2000-31006 and other research related to automatic milking have resulted in increased knowledge on management aspects with automatic milking. An overall picture of changes in management when milking with an automatic milking system however is not available.

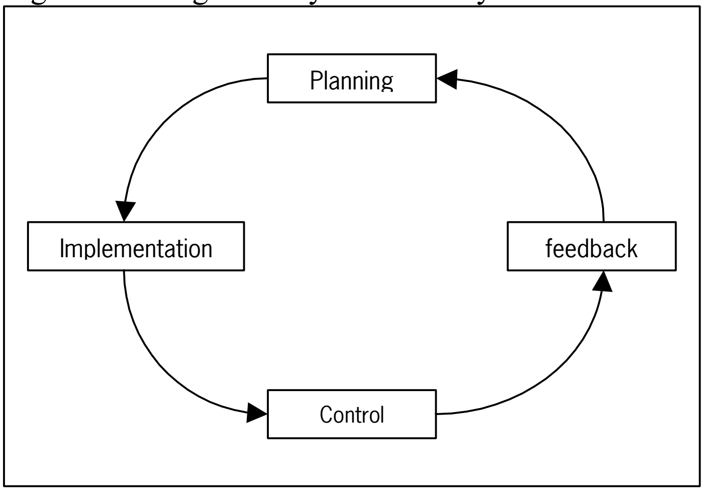
The objectives of this report are to generate a list of demands for operational management with automatic milking systems relative to conventional milking, compare this list with the possibilities of currently available systems, signal shortcomings, indicate possibilities to overcome these and indicate further possibilities. This information is useful for manufacturers for further improvement of their products. For farmers the information can be used to support decisions whether or not to invest in automatic milking, and after having invested herein to improve operational management.

2 Management of dairy farms

2.1 Management cycle

Management is generally described with the so called management cycle of planning, implementation and control (Jalvingh, 1992; Devir et al., 1993; Pietersma et al., 1998). It is schematically represented in figure 1.

Figure 1 Management cycle of a dairy farm



Planning consists of defining goals and selecting a course of action to accomplish these goals. Implementation refers to acquisition of necessary resources and putting the plan into action. Control consists of record keeping, evaluating the performance and taking corrective action if necessary (Pietersma et al., 1998). This is a continuous process. Furthermore usually a distinction is made between strategic, tactical and operational management levels, based on the different time horizons. Operational management refers to short term day to day management and control activities, within a given farm structure. A further distinction is made by Pietersma et al. (1998), who also mention a regulatory management and control level. This level refers to very short term (minutes or seconds) activities, which take place continuously. In reality the distinction between activity levels is gradual.

Most farmers are both responsible for decision making and physical activities. On large farms proportionately less time is spent on physical work, and more time is spent on decision making (Tomaszewski, 1993). Some management tasks can be automated completely, whereas others require human involvement and are more suited for decision support systems. Especially at regulatory and operational level, automation is often possible because decision making is relatively simple (Pietersma et al., 1998). Both sensor technology and process control systems are used for automation of activities. If traditionally mainly physical farm activities such as milking or feeding are completely or partially automated, this further reduces the amount of required labour, but introduces additional decisions to be made. Moreover it requires maintenance of the equipment and monitoring of its functioning. With increasing autonomy the demand for sophisticated control mechanisms also increases. In case of failures or disturbances of automatic milking the farmer should be alerted, and usually human interference is required.

Decision making can be more than just making final choices (Pietersma et al., 1998), because the management and control activities are nested in a hierarchical model so at lower level additional decisions may be needed. Implementation of a decision can be a physical activity but can also lead to a new cycle of decision making. Implementation of strategic plans is mainly virtual, because it requires additional decision making at lower levels. At the regulatory level implementation is mainly a physical activity.

2.2 Decision making, sensors and information

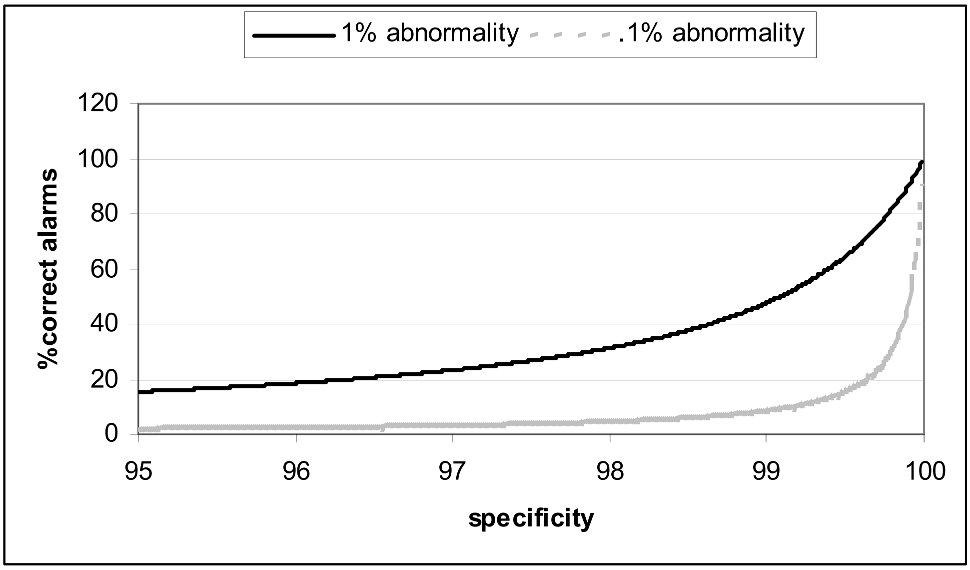
Part of the management tasks of the farmer is to make decisions. Detection and diagnosis of problems or opportunities is part of decision making, as is development and analysis of alternatives and selection of follow up action (Brand et al., 1996). Decision making thus is mainly based on information. Traditionally farmers obtain information for decision making from various sources: eyes, ears, nose, feeling but also from experts and figures from management systems and e.g. milk recording. Nowadays information can also be obtained from computerized systems equipped with sensors. Electronic cow identification, which is on the market since 1976 (Tomaszewski, 1993), is a key element in such systems. Computerized systems are particularly useful to support human decision making if more than one person is handling the cows (Spahr, 1993). As signalled by Tomaszewski (1993) and Pietersma et al. (1998) a growing amount of available data only improves decision making if sensor systems are reliable and the data is utilized appropriately. Integration of information supports correct utilization. This implies exchange of information from different sources, also within the farm. It requires that well defined standards are used for this information, and that software is compatible.

Sensors can register data that is traditionally observed by humans (e.g. milk yield, cow activity), but they also allow additional variables to be measured (e.g. milk temperature, conductivity). Use of sensors leads to an enormous increase in the amount of data that can be stored, treated and interpreted. Often the data are primarily collected to control their level in time and detect possible problems. Important categories of problems are health problems and abnormal milk. Typically the sensors measure parameters that are correlated with the true variables of interest. If sensor readings are outside the normal range the likelihood of true abnormalities is relatively high, and an alarm is generated. In case of alarms there should be follow up action, either a check by the farmer or on-line decision making by the AMS such as separating abnormal milk. This way of managing is called management by exception. The alarm is considered True Positive (TP) if an abnormality exists, and False Positive (FP) if no abnormality exists. If no alarm is generated we have a False Negative (FN) situation when an abnormality does exist, and a True Negative (TN) when no abnormality does exist. The performance of sensor systems (sensors and software) for detection of abnormalities is generally described in terms of sensitivity (% of problems detected: TP/(TP+FN)*100) and specificity (% of non-problems classified as such: TN/(TN+FP)*100). Sensitivity and specificity can be influenced by changing thresholds for alarms. Increasing sensitivity with the same sensor in general decreases specificity. A low sensitivity means that a substantial part of the abnormalities are not detected in time by the sensor system. Low specificity means that many alarms are FP.

What consequences does a certain specificity have for automatic separation? As an example assume a farm with 100 cows, 2.5 milkings/cow/day and 310 days in milk per cow per year. Thus there are 77.500 milkings in a year. With 50 cases of clinical mastitis each year, and 10 milkings with abnormal milk for each case of clinical mastitis, 500 milkings are abnormal or .64% of all milkings. The remaining 77.000 milkings are normal, but with a specificity of 99% 770 of these milkings are getting an FP alarm. If all milk from milkings with alarms would be separated and assuming the average production is 10kg of milk in total 7700kg of normal milk would be separated unnecessarily. With a specificity of 95% 38.500kg of normal milk would be discarded, which is clearly unacceptable for automatic separation.

Visual abnormalities indeed are exceptions, and occur with frequencies in the order of .1% to 1% of all cases. This particularly has consequences for the reliability of alerts. In figure 2 the percentage of alarms that are TP (TP/(TP+FP)*100) are presented for these 2 frequencies of abnormalities. A sensitivity of 90% is assumed, but this only has a minor influence on the figures.

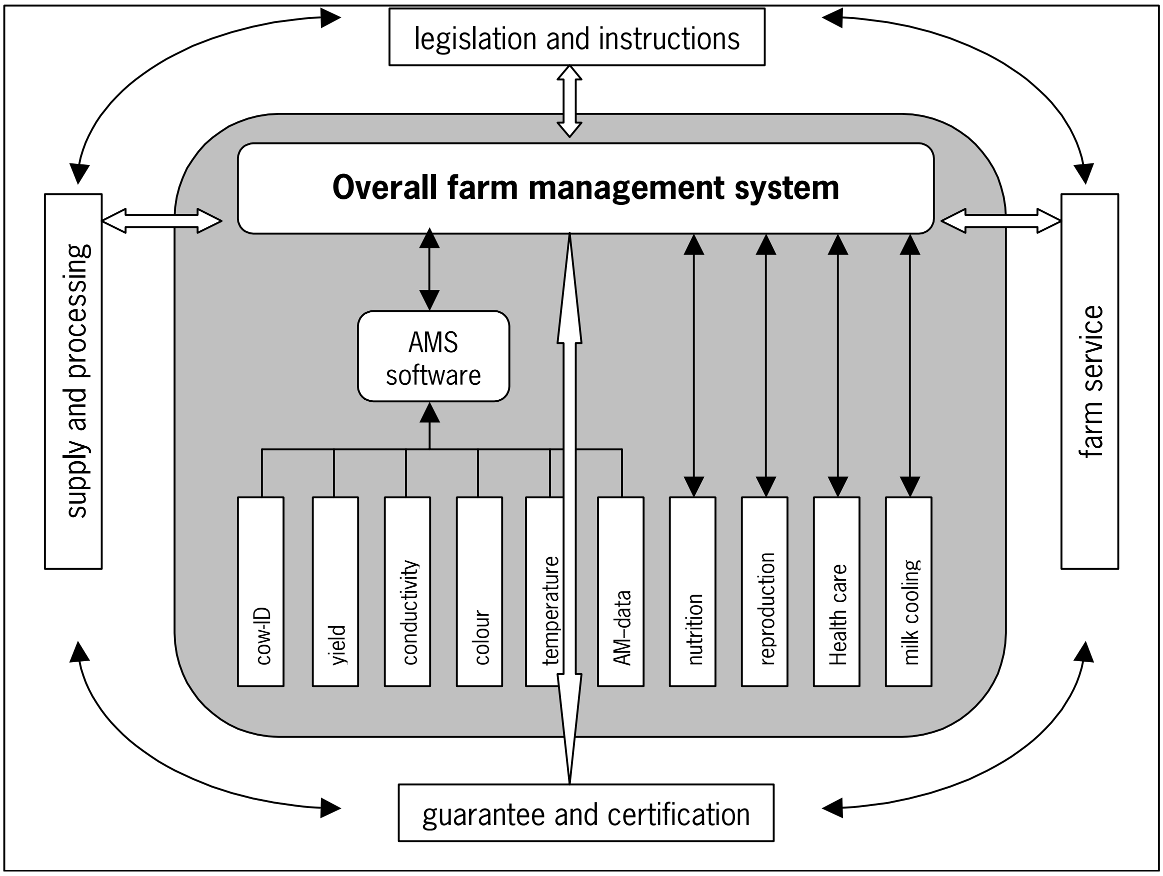
Figure 2 Relationship of specificity and percentage of correct alarms for 2 frequencies of abnormalities



This figure clearly shows that especially with low incidences of abnormalities a very high specificity is required to get a reasonable percentage of correct alarms. The requirements for practical use are very dependent on the way the information is to be used. Automatic separation requires a very high specificity, whereas with manual checks of alarms a lower specificity is acceptable. If detection of abnormalities is not completely based on but supported by sensor information a lower sensitivity is acceptable than when detection of abnormalities is solely dependent on sensors.

A decision support system (DSS) is characterized by the fact that a human takes the final decision, but with the help of a more or less specific recommendation based on available information. Knowledge based systems are built on expert interpretation of sensor data. They can be used to generate understandable recommendations for problems that are generally poorly understood by farmers (Pietersma et al., 1998). Some management and control activities can be performed off –farm, especially when they require special expertise and are not too frequently used, for instance feed ration formulation. Operational and regulatory activities such as heat detection and mastitis detection are to be performed on the farm. A schematic representation of information flows on a dairy farm is presented in figure 3.

Figure 3 Information flows on a dairy farm with an automatic milking system



This figure clearly indicates that besides information from the AMS software and sensors also other information is used by dairy farmers to manage the farm, and that information is exchanged both within and outside the farm.

With automatic milking systems it is possible to collect enormous amounts of data. For instance measurements in milk can be performed every second during milking in each quarter. It is clear that it is impossible to take a close look at such vast amounts of data, and that this will only be useful information when processed with sophisticated software. Even with currently available hard disks it is impossible to store all this primary data. In principle this is also relevant for conventional milking. So the storage and processing of sensor data requires attention (Spahr, 1993). In order to be beneficial for the dairy farmer, the information gathered with computerized systems must have obvious benefits and its use easy to learn. If information can be obtained otherwise at lower cost or in a timelier manner it will not be attractive to use sensors (Spahr, 1993).

Both to take decisions and to perform tasks that are regarded as physical activities information is used. An example is cluster attachment by the milker. First he or she has to find the teats and then can attach the teat cups. This type of information is normally not stored or used for decision making at a later stage, only general knowledge on udder shape and teat placement may be stored in the milker's head. So two types of information can be distinguished: decision supporting and regulating information. Regulating information does not need to be stored for management purposes, unless the farmer has to check the performance of the automated process. It could be stored on the background for servicing purposes.

2.3 Operational management functions

Brand et al. (1996) give an outline of the management structure of a dairy farm. Following the subdivision of a dairy farm into the production unit's roughage production, young stock raising and milk production, only the milk production section is worked out in this report. It is likely that the other two sections are not essentially different for farms with conventional or automatic milking systems. With this limitation the following operational management functions and underlying sub functions (as distinguished by Brand et al. (1996)) are listed in table 1.

Table 1 Operational management functions

Function	Sub functions
Nutrition	Grassland utilization, ration composition, control of feed supply, grazing/feeding, body condition scoring, assessment
Health care	Observation, examination, prevention, treatment
Reproduction	Observation, insemination, examination/treatment, calving assistance
Milk production	Milking, storage, milk testing, assessment
Herd replacement	Sale (including selection), purchase
Fixed assets and labour	Acquisition, maintenance, hiring
Cash management	Borrowing/investing, payments/receipts

Each sub function can be divided further in a number of processes. In this report this is done for the milking sub function, because this is a key issue in automatic milking. The herd replacement function suggests that replacement heifers are bought from elsewhere, but closed herds are propagated in The Netherlands in order to reduce risks of introduction of infectious diseases. So it is meant as a within farm purchase. Although in principle each function also contains an assessment sub function, these are only mentioned if they are to be used frequently.

The above classification is somewhat arbitrary, because activities can often be linked to more than one function. Welfare is regarded as part of health care and not as a separate operational function. With regard to the operational functions farmers can have their own specific goals, besides the general objective of economic efficiency. For instance with feeding an objective could be to minimize nitrogen losses. Realization of optimal milk quality also deserves attention for dairy farms with automatic milking systems (Van der Vorst et al., 2003). Because of growing awareness within the European community regarding food safety issues minimizing hazards for food safety problems becomes more and more important. The different goals have their consequences for the operational management functions mentioned above. Decision making at tactical and especially strategic level usually involves the whole herd, so it cannot be confined to separate functions (Pietersma et al., 1998).

2.4 Categorization of management tasks

As mentioned above the primary task of a farm manager is to plan, execute and control activities. Because of the variable degree of complexity of processes to be managed, Devir et al. (1993) have mentioned short term management control and process control. Management control refers to decisions or actions that are taken by the farmer based on the cow's individual performance. Decision support systems can assist the farmer with this task. Process control is described as the examination of an automated process in order to decide which actions to take. The two sorts of controls differ in the rapidity of decision making and the farmers involvement in the decision making process. The farmer has no direct influence on process control, because decisions are taken on-line. Decision variables however can be set and changed by the farmer. The paper of Devir et al. (1993) is basically focused on access-criteria and managing milking intervals. A similar distinction was mentioned by (Pietersma et al., 1998), who indicated management and control activities. Management activities refer to complex, sometimes vague and often long term decisions, which mostly require human participation, and control activities refer to simple, well defined and often automated activities. Both types of activities imply some kind of management cycle with decision making (which action is to be undertaken), implementation and feedback.

Automatic milking systems basically perform tasks that traditionally are physical activities a farmer normally takes care of himself, like many other forms of mechanization. As stated before, this requires additional decision making by the farmer or his advisors (Pietersma et al., 1998). Therefore a farmer’s task becomes one of management and supervision (Meskens et al., 2001). In order to support decision making (including monitoring automated processes) these systems produce an increasing amount of information. The interpretation of this information does require human involvement because it otherwise would have been computerized (Pietersma et al., 1998), but should not be too complicated. Combining and integrating information from different sources facilitates the use of the information. The makeup of alert lists deserves attention. If deviations from expected values occur it is not always clear what to do next. Protocols or guidelines could support the farmer with the follow up.

3 Differences with automatic milking

3.1 Nutrition

One of the objectives of automatic milking is to increase milking frequency and thus production per cow. Increased production requires good feeding strategies and feed quality (PR, 1992) and Rougoor (1999) reported that a high production per cow is economically not attractive for all farmers. Even without a production increase with automatic milking the feeding strategy may have to be adapted in order to have regular spreading of cows visiting the milking unit. According to Wiktorsson et al. (2003) it is primarily important to always have roughage available in the feeding area, the frequency of distributing roughage is less important. Temporary unavailability of feed for individual cows, for instance due to controlled cow traffic, is allowable. In the study of Van der Vorst and Ouweltjes (2003) more than 50% of the farms supplied roughage only once a day. Although grazing is possible in combination with automatic milking (Van Dooren et al., 2002; Krohn, personal comment 2003), it is likely that relatively more roughage will be consumed inside the barn. This however also happens with larger farms with conventional milking systems. If farmers want to apply grazing strategies, maintaining system capacity deserves special attention (Van Dooren et al., 2002). In general a diurnal grazing pattern was found, in which cows tended to graze more in afternoons and evenings and stay indoors during late night and early morning. This affected the visits to the milking unit. Feeding supplementary roughage can be used to stimulate cows to return to the barn. According to Spörndly and Wredle (2002) restricted supplementation is as effective as ad libitum supplementation.

Feeding concentrates probably is a better motivation to visit the milking unit than being milked (Ketelaar-de Lauwere, 1999; Prescott et al., 1998). In addition to being a better motivation for visiting the milking unit, it has also been observed that feeding during milking increases the milking related oxytocin release, which affects milk flow and milking time (Johansson et al., 1999). Not surprisingly, in practice cows are usually attracted by feeding concentrates in the milking unit (Van der Vorst and Ouweltjes, 2003). This might affect the benefits of feeding total mixed rations, as they are jeopardized when more than 10% of dry matter intake is fed separately (Roodenburg and Wheeler, 2002). The allocation of concentrates has to be adjusted to the desired milking intervals, especially when part of the concentrates are fed outside the milking unit. Ration formulation, which is an activity at tactical level, is not essentially different for automatic milking. Controlling body condition score, which is useful for operational assessment, is also not different, as is the process of monitoring feed intake. If feed intake is registered electronically at cow level it can be monitored automatically, but this is not necessarily related to automatic milking. If feed intake is not registered at cow level the regulatory assessment is basically to check the amount of food left over (in barn) or compare expected and realized milk production. The latter is dealt with in the milk production function. Because in some circumstances cows may have to spend long time periods in separated areas in the barn such as a waiting area, the availability of drinking water in these areas deserves extra attention. Quality of drinking water in general deserves more attention (Ouweltjes et al., 2003), not only in combination with automatic milking.

3.2 Health care (including welfare)

Health care is traditionally largely based on visual observation of cows around milking (Hillerton et al., 2003) and for udder health also on visual inspection of foremilk. Visual inspection of foremilk is handled under “milk production”. The absence of the herdsman during milking means that this type of information, as far as it is collected around milking, is missing. Some of this information *must* be collected during milking (foremilk), other information can also be collected at other times during the day. If it will be required that milk that enters the bulk tank is from healthy cows (EU, 2000), a health check must be carried out before or during milking, including inspection of the teats for injuries. So to some extent it can be required that information is collected and interpreted automatically. Although disease incidences reported differ between studies, and within studies there is variation between farms (e.g. Stevenson, 2000), it can be concluded that milk fever, retained placenta, metritis, ketosis, displaced abomasum, cystic ovaries, lameness and mastitis are the diseases that occur most frequently in dairy cattle (Kelton et al., 1998; Osteas, 2000; Fleischer et al., 2001). Preliminary results of Hillerton et al. (2003) indicate that lameness and cell count may be somewhat impaired after introduction of automatic milking, but the study of Van der Vorst et al. (2002) showed that cell counts improved again after the introductory period.

With automatic milking systems a lot of information can be collected. In general this information is not reliable enough to automatically monitor whether a cow suffers from a certain health problem. For instance Hamann and Zecconi (1998) reported average sensitivity and specificity of 68 and 82% for detection of clinical mastitis based on electrical conductivity. Improved algorithms however could greatly enhance the performance of currently available sensors (De Mol and Ouweltjes, 2001; De Mol and Woldt, 2001). The information from sensors can be useful for decision support, and could help to detect and treat a disease in the sub clinical stage (Milner et al., 1996). The herdsman can give extra attention to cows with alarms, which is true management by exception. Because there is a variety of parameters that can be measured, detected deviations can refer to various causes. If alerts are generated with the information from only single sensors, as is the case for current automatic milking systems, the herdsman first has to combine the available information to improve diagnosis. A low milk yield in combination with high activity could indicate heat, low milk production in combination with low feed intake could indicate digestive problems and low milk production and high conductivity indicates udder health problems. The extent to which parameters are outside their normal range is related to the probability that the alarm is true. In combination with the improved diagnosis this probability could be used to determine which follow up to perform to come to a final diagnosis. Automatic separation of milk could be activated above a certain probability. A difference with conventional milking with sensor information in the parlour is that it is not possible to immediately check the cows that are alerted for some reason, so the decisions have to be made at a later stage, with the help of alarm lists. It is likely that cows that are really ill do not visit the milking unit in time and will appear on an alert list for long milking interval (Jagtenberg et al., 1997), so the more severe cases can probably be detected visually before milking. The decisions on setting thresholds for alarms and applying strategies to check cows with alerts are tasks for the farmer.

Once cows with health problems are detected and diagnosed, they have to be treated by the herdsman or further inspected by the veterinarian. This is not really different for automatic milking, but because sensor information plays a role in detecting animals with health problems it may be helpful if the vet gets a brief report of abnormalities that were found with sensors. Of course the vet should be able to interpret these data. After first treatment the recovery of the animal has to be monitored, and sensor information could be used for this purpose if the treated cows are still milked in the automatic milking unit. With regard to antibiotic treatment it is mentioned that with low milking frequency excretion of residues may be prolonged (Knappstein, personal comment 2003). Therefore farmers have to take care that treated cows are milked at least twice a day. At the end of the withholding period udder health should be checked both for automatic milking and conventional milking, because cell counts may still be high and it may be necessary to withhold milk for a longer period than the official withholding period. It is of great importance that treatments and withholding periods are entered into the management system of the automatic milking unit so that milk can be separated if needed. This is facilitated by using protocols. Because cows sometimes are milked sooner than expected, Knappstein (personal comment, 2003) suggests excluding cows from milk delivery before treatment, especially when they are presented to the vet and treatment with antibiotics is expected. If for overall herd management separate management software is used, exchange of information with the milking unit software is strongly recommended.

It is also considered important to take preventive action. This requires a prevention plan to be made, executed and evaluated regularly. For udder health proper functioning of the milking equipment is important. Actions to prevent spreading of pathogens with the milk cluster, such as milking infected cows after the other cows, are more easily applicable in conventional milking systems than in automatic milking systems. In AM-systems teat dips have to be sprayed instead of dipped. Neijenhuis and Hillerton (2002) advise to monitor teat condition in order to detect problems related to milking technique. If grazing is reduced more attention is needed for housing comfort. Wiktorsson et al. (2003) state that observations on fur condition and bruises are useful to detect housing problems. According to Spörndly and Wredle (2002) locomotion status does influence milking frequency. Because regular voluntary visits to the milking unit are important, extra attention for good claw health is warranted. Health assessment at herd level, directed to calculating and interpreting herd health figures, is more at tactical level, and not a day to day activity. Due to the nature of the underlying figures more frequent assessment is not useful.

Traditionally in dairying animal welfare was not considered problematic and did not receive much specific attention. It was for instance not mentioned as a separate management item by Brand et al. (1996). However it is becoming an important issue recently. Although it is recognized that operational management has considerable effects on animal welfare (Sørensen et al., 2001), assessment of welfare is not a day to day activity and needs to be implemented in an extension framework. It is useful for decision support regarding operational management changes. A protocol to assess animal welfare at herd level in herds with automatic milking systems is described by Hindhede et al. (2002). With regard to welfare automatic milking could be difficult for low ranking cows, because they have access to the milking unit at unfavourable times of the day. Millar (2000) argues that if access to primary or secondary needs is only available through the milking unit, more aggression may occur. However, Wenzel (2001) states that sufficient care and measures to reduce stress are important to prevent stress. According to Wiktorsson et al. (2003) low ranking cows do not show signs of stress (based on cortisol and oxytocin) compared to high ranking cows when milked automatically, indicating that their welfare is not lowered due to automatic milking. This is in line with results of Hopster et al. (2002).

3.3 Reproduction

The reproduction function contains the following activities: heat detection, insemination, examination of cows with fertility problems (not showing heat or repeat breeders) and pregnancy checking. This is with the assumption that cows are artificially inseminated and the farm uses veterinary fertility services. Although not indicated by Brand et al. (1996), drying off also could be included in this function. The last activity in this function is calving assistance. These activities are linked with the functions milk production and health care. Furthermore reproduction is linked with herd replacement, which is also regarded as a separate function.

Differences with conventional milking appear in the area of heat detection. With conventional milking the farmer sees all cows at least twice a day, and is then able to detect cows in heat, although Van Eerdenburg et al. (1996) advise to observe the cows for heat detection two to three times a day after milking and feeding for about 30 minutes. The herd is less synchronized with automatic milking, this could influence behaviour and thus heat detection. Although heat detection can be supported by information from sensors, it is currently not possible to detect heats in a completely automated way (Firk et al., 2002). At least animals with detected deviations that indicate possible heat have to be visually checked by the herdsman in order to confirm heat. Relying on these alerts requires a low percentage of false negative alerts, but this is feasible with currently available technology (Firk et al., 2002).

Preliminary results (Hillerton et al., 2003) indicate that automatic milking is not related to body condition score. Kruip et al. (2002) concluded that automatic milking did not have apparent negative effects on fertility, but on average showed longer intervals to first service. It is speculated that this is mainly caused by lower intensity of heat detection on farms with automatic milking systems in practice and not due to a lower energy balance or other physiological changes.

Sire selection could be different because of differences in breeding goals. Checking of cows by a veterinarian or technician is not different for automatic milking. Drying off is a typical management decision of the farmer that could be supported with information on milk yield and udder health. If the capacity of the automatic milking system is fully used it can be attractive to dry off low producing cows relatively early. Apart from this there is no information supporting a specific approach for automatic milking, so it is assumed that operational management is similar. Lowering milking frequency towards drying off date stimulates cessation of milk synthesis, and is a common practice in some countries (Lacy-Hulbert et al., 1999). Sometimes drying off is delayed because cows still produce a lot of milk. If automatic milking systems, allowing milking frequencies to be set for individual cows, would be able to reduce targeted milking frequency during the last part of the lactation just before drying off in a predefined way, the metabolic change from end lactation to the dry period could be diminished. This could improve drying off. Bulk milk quality may also be improved, because increased FFA-levels are common for AM-herds (Van der Vorst et al., 2002; Van der Vorst et al., 2003) and milk of late lactation cows is more susceptible to lipolysis than milk from early lactation cows. After calving the system managing the automatic milking unit has to be updated, in order to allow a cow to be milked and fed concentrates, and the colostrum to be separated. If needed milk can also be separated automatically after the colostrum period if the withholding period due to dry cow therapy is not ended. Reproduction assessment is more at tactical level, and not a day to day activity. It is directed to calculating and interpreting herd fertility figures, and adapting herd management if deemed necessary. Due to the nature of the underlying figures more frequent assessment is considered not useful.

3.4 Milk production

3.4.1 Entering the milking unit

The most noticeable difference between conventional and automatic milking is that with currently available automatic milking systems cows are milked individually and preferably visit the milking unit voluntary, instead of forced group wise visits in conventional systems. Therefore with automatic milking cow traffic is important for successful farm operation. Although it is preferred to have free cow traffic, in some circumstances selection gates are almost necessary to utilize system capacity. Van Dooren (personal comment, 2003) stated that this is the case when grazing is applied. Teaching of heifers is probably more important than in conventional systems. As mentioned before feeding is a key factor in managing cow traffic.

In the current setup of automatic milking systems, compared to conventional milking some additional decisions have to be taken. Typically with conventional milking the farmer decides on the milking interval for each group of cows. With voluntary individual access to the milking unit, for each cow that visits the milking unit or a selection gate it has to be decided automatically whether she should be milked or not. Secondly, it has to be controlled that cows do not stay away from the unit too long. So far this requires human intervention. Van Dooren et al. (2002) indicate the importance of repeated daily patterns and to prevent the cows from getting used to being fetched, and mention that cows need time to get into a certain rhythm. According to Krohn (personal comment, 2003) farmers had to fetch most of the cows at the end of the day when grazing was allowed during daytime. For herds with on average ±60 cows this took 5-50 minutes/day. In order to avoid queues in front of the robot the number of cows fetched at one time should be limited. The farmer also has to control the realized milking intervals, and regularly evaluate the applied access criteria. Van der Vorst and Ouweltjes (2003) report that the majority of Dutch farms used free cow traffic. The study of Wiktorsson et al. (2003) indicated that forced cow traffic with a by-pass gate resulted in a low percentage of cows to be fetched for milking. This traffic system was more satisfactory than forced traffic without a selection gate or free traffic. Also Spörndly and Wredle (2002) reported more cows to be fetched and a lower milking frequency with free cow traffic compared with semi-forced traffic. Offering drinking water inside the barn only seemed to increase milking frequency somewhat, but this is not preferable from welfare point of view. Individual auditory signals as a means to stimulate cows to visit the milking unit are tested by Spörndly and Wredle (2002). Preliminary results show no increase in milking frequency, although cows can learn to respond to these signals.

Furthermore, besides feeding, cow traffic and fetching strategy, barn layout is important for regular voluntary visits of cows to the milking unit. This however is merely a matter of strategic or tactical management. When cows are allowed grazing, both field distance and availability of grass in relation to supplementary roughage level seem important for regular voluntary visits of cows to the milking unit (Van Dooren et al., 2002; Spörndly and Wredle, 2002), although Ketelaar-de Lauwere et al. (2000) reported no effect of field distance on visiting frequency for field distances up to 400 meters. Furthermore hot weather influenced milking frequency. Spörndly and Wredle (2002) concluded that successfully combining automatic milking with grazing requires continuous adaptation of management with changing circumstances. Tactical planning regarding capacity, milk yield and labour determine how access criteria have to be set.

3.4.2 Teat cleaning and udder preparation

After a cow has entered the automatic milking unit and is to be milked the milking has to be performed. For prevention of mastitis it is recommended to first remove the first squirts of milk, but all automatic milking systems perform teat cleaning before or simultaneously with foremilking and udder preparation. In conventional milking systems a worker is present to judge whether the teats and udder have to be cleaned, perform the cleaning and asses the result. With this check teat injuries can be detected as well (Mottram, 1997b). In high capacity milking parlours however, time is lacking to really inspect teats. In automatic milking systems the teats are usually only cleaned in a standardized way, without checking cleanliness or injuries before or after cleaning (Knappstein et al., 2002). Several principles of teat cleaning are used with AM systems (De Koning, 2002): sequential cleaning by brushes or rollers, simultaneous cleaning by a horizontal rotating brush, cleaning with water in the same teat cups as used for milking and cleaning by a separate teat cup like device. Especially for systems with brushes or rollers, it is important that cleaning height is correctly adjusted for each cow, and that the teats are indeed touched. Although in some systems the cleaning intensity can be adjusted, no distinction is made between clean and dirty cows. With conventional milking cows with dirty udder or teats can be cleaned more intensively. Milking of cows with dirty teats can adversely affect bacteriological quality of raw milk and is a risk factor for mastitis. Although automatic cleaning of the teats has proved to be very efficient with regard to reduction of the number of spores on the teats (Melin et al., 2002), management practices to keep udders clean, such as clipping udders and use of clean bedding material, are important to ensure that cows are milked with clean teats. All currently available systems use wet cleaning, some are able to dry teats after cleaning. Wet cleaning increases the risk for mastitis compared to dry cleaning. There are differences between systems in cleaning efficiency (Knappstein, personal comment 2003), indicating improvements are possible. The unit that cleans the teats should be cleaned before the next cow is cleaned, especially in order to prevent spreading pathogens. If during cleaning a disinfectant is used the supply level should be checked manually or automatically. Maintenance of the teat cleaning device, for instance replacing brushes, is important to ensure cleaning efficiency.

Udder preparation in conventional milking is usually part of a standardized working routine in the parlour, and as such is comparable with automatic milking systems although the work is automated (in some conventional milking systems this is the same). The procedure in automatic milking units probably is more uniform than with conventional milking, but Bruckmaier et al. (2001) state that teat cup attachment usually takes more time and can be delayed in automatic milking systems. Improvement is possible because techniques used for teat detection and attachment are still developing. One of the objectives of automatic milking is to increase milking frequency, and short milking intervals will occur in practice. Neijenhuis and Hillerton (2002) argue that with short milking intervals more effective stimulation is necessary to avoid long machine attachment time and overmilking. Mein and Thompson (1993) state that higher producing cows have lower premilking stimulus requirements. Inadequate teat preparation affects milk quality and the risk of infection. Bruckmaier et al. (2001) conclude that teat cleaning devices in automatic milking units sufficiently stimulate milk ejection.

3.4.3 Inspection of foremilk

Before the milking cluster is attached the foremilk should be inspected visually according to current EU-regulation, and when the milk is abnormal the milk should not be milked in the bulk tank. As with teat inspection time may be lacking to really inspect foremilk in high capacity milking parlours, but theoretically the possibility exists. With automatic milking milk samples have to be inspected with sensors, and abnormal milk (see Rasmussen (2003) for a definition of abnormal milk) should be separated automatically. Also milk that is considered contaminated or undesired (Rasmussen, 2003) should be separated, but this does not require milk inspection. If milk is considered abnormal the farmer has to be informed about this. For some systems the farmer has to set thresholds and furthermore he has to find reasonable intervals to check cows with alarms and interpret the information. Before milk can be inspected it has to be extracted from the cow, this requires teat detection and attachment of premilking teat cups. Some automatic milking systems however use the regular teat cups to obtain foremilk and separate this foremilk from the rest of the milk. This can enhance the system capacity. Other systems combine teat cleaning and foremilking and use separate teat cups for milking, one system combines teat cleaning, foremilking and milking and automatically separates cleaning water and foremilk from the milk to be stored in the bulk tank.

Apart from preventing abnormal milk to be milked in the bulk tank and enter the human consumption chain, inspection of foremilk also is important to control udder health. Abnormalities can indicate udder health problems such as mastitis or teat injuries. Together with other sensor information this can be used to generate alerts. This is handled under health care. Although probably not suitable for automatic separation, inspection of the in-line milk filter in the delivery line to the bulk tank could play a role in detecting abnormal milk and thus cows with udder health problems.

3.4.4 Teat cup attachment

Next step in the milking process is attachment of the teat cups. In conventional milking the farmer detects the teat placement visually, and attaches the cluster. Automatic milking systems detect the teats with help of sensors and use a robotic arm to attach the teat cups. Artmann (1997) suggested that teat detection sensors could also be used to inspect teats for cleanliness and injuries. Different manufacturers use different techniques for teat detection and attachment (Atrmann, 1997). Solving this problem was a major step in the development of automatic milking systems, especially because cows can move during cluster attachment (Ordolff, 2001). Although attachment has improved significantly, still failures do occur (Neijenhuis and Hillerton, 2002). Attachment failures especially occur for cows with poor udder conformation. Interference of farmers with automatic teat cup attachment by helping the robot may negatively influence attachment rates (Knappstein, personal comment 2003). The time taken to attach all teat cups may influence let down of milk. Therefore attachment failures not only can cause some discomfort for the cows, but also could stimulate milk leakage (Stefanowska et al., 2000) and can affect udder health. Because not all cows are milked on four quarters the systems should have the possibility to skip quarters, preferably also during teat cleaning and udder preparation. It should be checked whether the right attachment criteria are used for a certain cow, and that she for instance is not milked on only 3 quarters while she has four normal quarters. The speed with which the above steps are performed to a large degree determines the capacity of a milking unit (De Koning and Ouweltjes, 2000). The success ratio of attachments per quarter can be calculated for each unit to detect technical failures, and for each cow to indicate problem cows. At cow level attachment problems might be due to udder shape or kicking behaviour.

3.4.5 Milking

Because with increased production level and milking frequency machine on time per cow increases, proper milking technique deserves attention (Mein and Thompson, 1993). The process of milking itself is not different from conventional milking, automatic milking systems also comply with ISO-standards regarding pulsation ratio, vacuum level and capacity (Neijenhuis and Hillerton, 2002). The vacuum stability is different for automatic milking, and quarter milking reduces the possibilities for spreading of pathogens between quarters of the same cow. With conventional milking systems human interference normally is not required during milking, but only when a cow kicks off the cluster or teat cups otherwise drop off. First the teat cups and eventually the teats have to be inspected, if necessary they have to be cleaned and the cluster has to be attached again. Furthermore it has to be prevented that dirt is milked into the bulk tank before the cluster is attached again. With AM systems these steps have to be taken care of in an automated way.

3.4.6 Teat cup detachment

When the farmer takes off clusters manually he decides based on visual assessment of milk flow. In many conventional milking systems this part of the milking process is already automated, and based on objectively measured udder milk flow. With some AM systems teat cups are taken off per quarter instead of as a complete cluster, based on individual quarter milk flow. With regard to udder health this is a potential advance (Neijenhuis and Hillerton, 2002), but with regard to operational management teat cup detachment does not differ for automatic milking and conventional milking.

3.4.7 Cow handling after teat cup detachment

After teat cup detachment the teats can be treated with a disinfectant, according to the farmers preference. Preferably treatment can be switched on and off for individual cows (ISO, 2003). It is important that the agent does not give residues after teat cleaning (EU, 2000). If done manually, the farmer usually checks the supply of agents, dips the teats in the agent and could check whether all teats are dipped well. In automatic milking systems the supply of disinfecting agent can be monitored manually, but bringing the agent to the teats has to be automated. Therefore these systems use spraying devices (Neijenhuis and Hillerton, 2002), but these do have shortcomings. When sprayed to achieve sufficient coverage to manage teat condition the agent used spreads relatively widely. Therefore automatic milking systems use much more agent than needed to cover the teats. It also does not help to maintain the AM system clean. After the milking and eventual disinfection is completed the cow has to leave the milking unit. In order to maintain capacity this has to occur quickly. In a conventional parlour the milker can stimulate the cow to go. In automatic milking systems other stimuli can be applied, but these have to be acceptable from a welfare point of view (this is doubtful for electric stimulation) and should not negatively influence voluntary visits of the system.

3.4.8 Milk transportation and cleaning

After milking a cow the milk has to be transported to the bulk tank (if it is normal milk) or to a separation device. A difference between automatic milking and conventional milking is that relatively small amounts of milk are transported each time, and that cows are milked throughout the day, with variable intervals between milkings. This has impact on cleaning procedures. In conventional milking systems usually the whole milking installation up to the bulk tank and the parlour are cleaned after each milking, and a new milking is started with a new sock filter. Automatic milking systems use 3 types of cleaning cycles: cluster flush, unit flush and system flush (Schuiling et al., 2001). A cluster flush is performed after every milking, in order to reduce the risk of transfer of pathogens. Usually only water is used. A unit flush is performed after milking a cow with abnormal milk and after some idle time. Again no detergents are used, but this cleaning takes more time and water than a cluster flush. System cleaning cleans the whole milking system up to the inlet valve to the bulk tank with detergents. In The Netherlands 3 times a day flushing the system is compulsory. Refreshing the filter in practice is not directly linked to system flushes (Van der Vorst et al., 2003), although this is recommended and could be automated (Schuiling et al., 2001). Cleaning of the area in and around the milking unit have to be done manually and are not combined with cleaning the milking installation as is usual with conventional milking. The study of Van der Vorst et al. (2003) showed the importance of good hygiene in relation to milk quality. This indicates that regularly cleaning the area in and around the milking unit contributes to good milk quality. Cleaning is also important for the image of milk as a safe food product.

3.4.9 Milk storage and cooling

Because milking is more or less continuous throughout the day it is likely that cows are milked while the bulk milk carrier arrives. Because it is unacceptable for the dairy industry to have the truck waiting, and also because the bulk tank has to be cleaned after emptying, special solutions are necessary. A buffer tank is a solution to temporarily collect and cool milk. It is recommended that the size of the buffer tank is 10% of that of the storage tank, but in practice buffer tanks are often larger (Wolters et al., 2000). A disadvantage of buffer tanks is that the cooling installation becomes more complex, therefore other solutions are applied such as a temporary stop of pumping milk to the bulk tank. Furthermore bulk milk tanks used with conventional milking systems usually are suited to cool relatively large amounts of warm milk entering the tank, but give problems with icing when a small amount of warm milk is to be cooled (Wolters et al., 2000). Once the right cooling system is installed, cooling does not imply differences for operational management. Some cooling systems are more automated than others (Wolters et al., 2000). A more complex cooling system does require more control (especially of cleaning) by the farmer. If setting of valves, starting of cleaning etc. are to be done manually, there are also more physical tasks to be done by the farmer and potentially more errors. For the driver of the truck the difference with conventional milking could be that he has to take care that the milk flow to the tank that is emptied is stopped and if applicable the milk is directed to the buffer tank. However, the dairy industry in many countries requires that this is automated and not a responsibility of the truck driver. The farmer is responsible for cleaning of the buffer tank when it is emptied.

3.4.10 Milking cows with other than normal milk

European regulations require cows with abnormal milk (especially cows treated for mastitis and colostrum cows, according to the definition of Rasmussen (2003) these are classified as contaminated and undesired milk respectively) to be milked after the other cows are milked, before washing of the machine, or with a separate machine. The purpose is to prevent milk residues from these cows to enter the bulk tank (so it must also be separated), and it also may help to prevent spreading of udder infections. If a cow is treated with antibiotics milk from all quarters must be separated, although separation of individual quarters is possible with some automatic milking systems. Partial separation of this milk is not allowed because residues can also be excreted in non treated quarters. Milking cows with contaminated or undesired milk after all other cows are milked is not applicable with automatic milking. Although automatic separation of milk from these cows is feasible without sensors, residues could be mixed with milk from cows milked after such cows and pathogens of infected cows could be transferred to healthy cows. Therefore a unit flush has to be started automatically after such cows are milked, whereas for cows with normal milk a cluster flush is considered sufficient. Neijenhuis and Hillerton (2002) estimate that these flushes mostly overcome the risks of transfer of pathogens. In order to be sufficient, farmers should take care that unit flushes work well especially when cows treated with antibiotics are milked automatically. A prerequisite is that the software managing the automatic milking system is up to date regarding calvings, treatments and milk to be separated. If the milk is from colostrum cows, the milk has to be separated and kept to feed to the calf (preferably a calf receives colostrum from its own mother). In practice this probably implies that colostrum cows are not milked voluntary, but brought to the unit by the farmer.

3.4.11 Milk recording and milk production assessment

Because robotic milking requires some kind of management by exception control of milk production is a continuous process. Milk recording of individual cows is generally regarded as a very useful tool for herd management, and is also used to collect data for breeding programs. Especially the latter requires data exchange between the farm and a central database. Usually production data for 24-hour periods are collected, which is relatively easy when milking intervals are fixed. With automatic milking and voluntary visits to the system, this is more complicated. Manual collection of milk samples with continuous milking is very costly, this should be done automatically. Besides that, it is not possible to collect samples that exactly describe a 24 hour period, so the data should be standardized with appropriate mathematical procedures (Friggens and Rasmussen, 2001; Peeters and Galesloot, 2002). Furthermore, automatic milking systems already collect a lot of information automatically (for instance milk yield, conductivity, concentrate intake) and potentially also could measure milk composition on-line. Milk yields as measured by the automatic milking systems with approved meters are already used for official recording schemes, whereas the other information currently is used on farm only. The reliability of the on-farm sensors is usually lower than the reliability of the equipment used for official milk recording, but it can influence the farmer's needs for additional information. For instance, with regard to udder health up to date information on conductivity is available for each cow and quarter, whereas for most farms with conventional milking installations visual inspection is the only means of monitoring udder health besides cell counting. The frequency with which cows are tested should be suited to these needs.

3.5 Herd replacement

Both with conventional and with automatic milking cows are culled and replaced. It is likely that the major culling criteria are similar, although udder shape is more critical with automatic milking (Thomassen et al., 2003). It is suggested to cull cows that are responsible for the majority of alarms, but with appropriate software the majority of false alarms can probably be filtered (De Mol and Woldt, 2001). If the alarms are true it is questionable if culling is the best option, maybe these animals can be treated appropriately and herd management could be adapted to reduce the number of future alarms.

In order to optimally utilize the system capacity the number of milkings per day should not fluctuate too much. Therefore a good match of culling and replacement is more important than with conventional milking. For the same reason a seasonal calving pattern is less attractive for automatic milking. This is a matter of strategic and tactical planning rather than operational management. It is assumed that automatic milking may have consequences for breeding goals and thus for sire selection. This too is management at a higher level than operational.

3.6 Fixed assets and labour

With regard to operational management acquisition or hiring of fixed assets and labour is not considered to be different between farms with automatic milking systems and farms with conventional milking systems. Because the type of work to be done changes from physical activities to supervision this could in reality affect the attraction of labour, but this is beyond the scope of this work package.

3.6.1 Maintenance of milking equipment and housing

As stated earlier it is the farmer who is primarily responsible for maintenance of his milking equipment. One of the tasks of the farmer in this respect is to replace liners. Recommended is to replace liners after a certain number of milkings, depending on the material they are made of. Because in automatic milking units much more cows are milked each day with the same teat cups (tenfold is a reasonable estimate), liners should be replaced relatively often. The study of Van der Vorst et al. (2003) indicates that in practice farmers with automatic milking systems delay liner replacement, although this is negatively related to bulk tank SCC. A good hygiene around the milking system and in the barn are both important for good milk quality (Van der Vorst et al., 2003). The area in and around the milking unit is not cleaned while the system itself is cleaned, so the farmer has to take care of this separately. According to Unrath and Kaufmann (2003) the farmer could be supported in maintaining a clean AMS by image processing, but the technology needs further development. Other tasks with regard to housing are maintenance of flooring and lying areas, climate control and control of illumination. Many AM-barns are fully illuminated day and night, but this does not seem to affect cows resting behaviour (Wiktorsson et al., 2003). From a welfare point of view a period of darkness is preferred (Ouweltjes et al., 2003).

The automatic milking systems also have some features that conventional milking systems do not have, such as a teat detection device, a teat cleaning unit and spray mechanism. These features are usually not cleaned during the regular cleaning cycle, and therefore have to be cleaned and maintained otherwise. Several parts, for instance brushes, have to be replaced after regular intervals. Further maintenance should be carried out by professional technicians according to maintenance schedules provided by the manufacturers, like in regular milking systems. Because automatic milking to a large extent relies on sensors, these deserve attention too during maintenance. As the capacity to perform extra milkings after a breakdown is limited, quick service in case of problems is more important for farms with automatic milking systems than for farms with conventional milking systems (Sonck, 1996). Especially in areas where public electricity supply is unreliable alternate means for operating the machine should be installed (ISO, 2003).

3.6.2 Labour

With conventional milking some important activities in the day to day working schedule are fixed. Therefore daily planning of activities has not received much attention with conventional milking, but it can be regarded as operational activity. With automatic milking the farmer has more freedom when to perform his tasks, and this is an important motivation to buy such systems (Meskens and Mathijs, 2002; Van der Vorst and Ouweltjes, 2003). The need for surveillance is higher for AM-systems than for conventional milking (Reinemann, 2003). Farmers using AM-systems indicate that they de indeed spend more time on observing the cows (Wauters and Mathijs, 2004). Despite this, these authors report an overall reduction of labour time of 20%. Sonck (1996) distinguishes between planned and non-planned activities, where non planned activities relate to alerts given by the system. Surveillance can be supported with protocols and action lists, but this is also possible with conventional milking. In the study of Van der Vorst et al. (2003) 2/3 of the farmers used fixed times to check alert lists. Sonck (1996) calculated that three times a day fetching cows with long milking intervals was optimal both with regard to labour requirement and with regard to milking intervals and milk production. For instance in order to prevent too long milking intervals some regularity seems necessary, although this reduces flexibility and it has to be prevented that cows get used to being fetched. To maintain optimal performance it is considered of importance that the farmer schedules this tasks and does not delay them. In regard to the urgency of alerts also a distinction can be made: some situations may require immediate intervention, whereas others can wait until a scheduled check is carried out. The frequency of checking information also has to be determined with regard to the farmer's goals. As one of the goals of automatic milking is to improve labour efficiency, it is important to structure the work to be done. Reinemann (2003) state that Good Management Practices could be very valuable management aids.

3.7 Cash management

Although automatic milking systems are capital intensive systems, with regard to operational management they do not directly influence cash management. The decision to buy an automatic milking system is one of strategic management, and in this work package it is supposed a farm is working with an automatic milking system. Therefore this function is not worked out in this report.

4 Demands

Demands with regard to automatic milking are addressed to both legislators, manufacturers and farmers. In general, legislators must formulate the regulations such that they can be fulfilled with both conventional and automatic milking, manufacturers must provide systems that can be operated accordingly, with reliable sensor systems and instructions for operation and maintenance and farmers must work with the systems according to these instructions. These demands are discussed in line with the operational management functions in table 1.

Probably one of the first demands for farmers to be working with automatic milking systems is that they have faith in the system, and feel comfortable with management by exception. Apart from the technical functionality of the milking system (does it do what is pretended, is it user-friendly) this is merely a requirement for farmers. Farmers with interest in computer technology are likely to fulfil this requirement (Meskens et al., 2001). When safety of animals, humans or the system is at serious risk the farmer should be alarmed immediately, if less serious problems regarding functioning of the system are detected alarms should be within a specified time. Manufacturers have to define when either of these is the case, and develop software to detect potential problems. In order to be able to manage the herd, information on each milking, data on non-milking visits, data on machine cleaning, alarms and milk samples must be stored and also should be accessible for the farmer. Service technicians should have access to system information. This again is a demand for the manufacturers.

Good and automated criteria for the milking unit to determine whether a visiting cow is to be milked or not are a clear demand, and these have to be related to the farmers goals. This requires the possibility to enter personal settings. Preferably, these criteria also allow lowering milking frequency shortly before drying off. These criteria not only have to address if a cow visiting the milking unit should be milked, but also when a cow will appear on an alert list for not entering the system. Thus milking intervals should be controlled at individual cow level. The system must be able to list cows due for milking and cows overly due for milking. Because fetching some cows will be inevitable for most farms, the farmer has to develop a fetching strategy that is related to the desired milking frequency. Besides more or less fixed factors like barn layout, flooring and system of cow traffic also more variable management factors determine the average visiting frequency of cows. Therefore milking intervals should also be assessed at herd level on a day to day basis in order to identify deviations. Preferably only deviations with a certain significance level are reported automatically. Development of criteria and software is a task for the manufacturers, setting variable parameters and checking alarms are tasks for the farmers. Protocols can be very helpful with follow up action.

Concentrates are commonly used as means to attract cows to the milking unit, but in many cases also separate concentrate feeders are used (Van der Vorst and Ouweltjes, 2003). Therefore the optimal allocation of concentrates must be determined and software developed by the manufacturers. Feeding information should be exchanged between concentrate feeders in the barn and the milking unit, so these devices should be able to communicate. When feeding concentrates is fully automated, the farmer should check concentrate intake (both at herd level and for cows with alerts) and should monitor the supply and order new supplies if needed, like with conventional milking.

Traditionally detection of diseases, especially mastitis, largely depends on observations during milking. As is actually required and most probably also will be in the future, milk that enters the bulk tank must be from cows that are not visibly ill (EU, 2000), indicating that before the milk is stored a general health check has to be performed. It is likely that this does include more than checking for abnormal milk, although the performance requirements listed by ISO (ISO, 2003) only mention a sensitivity >80% and a specificity >99% for detecting abnormal milk. As can be seen from figure 2 with these figures automatic separation could still result in a large percentage of unnecessarily diverted milk. Especially for herds with good (udder) health more than 90% of the alarms can be considered false. De Mol and Ouweltjes (2001) and De Mol and Woldt (2001) showed that improvement of software with currently available sensor systems can improve performance substantially, but currently available systems are not reliable enough to enable automatic separation (Rasmussen and Bjerring, 2004). In order to be able to fulfil the requirement to separate milk from unhealthy cows a more specific and objective definition of criteria is needed, but this is a task for legislators rather than for manufacturers of automatic milking systems. Because sensitivity and specificity depend on the practical circumstances test procedures must be standardized. It is likely that with conventional milking only milk with abnormal visual appearance is withheld from the bulk tank. The detection of abnormalities should be reliable enough to enable automatic separation, and the system must enable the farmer to list cows where health problems are suspected. Different standards for conventional and automatic milking should be avoided (Rasmussen, 2003). It is up to the manufacturers how they achieve a satisfying combination of sensitivity and specificity, but it is likely that combining sensors will give better results than using a single sensor. Measuring milk yield of individual cows with sufficient reliability is essential. The number of different signals and sensors, the reliability of each signal and the attached software all are relevant with respect to sensitivity and specificity. Abnormalities that are found must be reported as alerts. The farmer must be able to interpret the information from the milking system and combine this with other information he receives. Preferably different sources of information are integrated with software. Again protocols can be very helpful with follow up actions. Of course milk from cows treated with pharmaceutics must be separated automatically during the withholding period. Because the detection procedure is essential, it's functioning should be monitored continuously. Manufacturers have to provide sensors and software. Farmers have to take care that milk from treated animals is indeed separated, check alarms lists and potential problem animals and check the functioning of the system.

Before milking is started the udder and teats have to be clean (EU, 2000). All visible contamination from the parts of the udder in contact with the liners should be removed (ISO, 2003). Manufacturers have to provide milking systems with appropriate cleaning devices. With wet cleaning temperature and pressure of water should be controlled and information on failed cleaning events should be available. The result of the (standard) cleaning procedure should be monitored automatically or manually. For manual evaluation of teat cleaning the protocol described by Knappstein et al. (2002) can be useful for the farmer. As described by Ordolff (2003) evaluating udder and teat cleanliness by spectroscopy is possible. With this technology also blood on the teats can be detected. Technology to automatically monitor teats and teat cleaning however needs further development. Since teat cleaning is based on time and not on individual demands, management has to ensure a low frequency of dirty udders, which means that beds and alleys have to be cleaned often and kept clean. If disinfectant is used the level should be controlled by the farmer.

Currently legislation states that milk is inspected visually for abnormalities (EU, 2000), and foremilk must not be directed to the bulk milk tank. So if foremilk is milked with the teat cups that are also used for milking, separation of this milk should be possible, regardless of the inspection results (ISO, 2003). Abnormal, undesired and contaminated milk must be separated automatically. Definitions of abnormal milk are discussed by Rasmussen (2003). Both homogeneity and colour are mentioned as elements, particularly with abnormalities caused by clinical mastitis (homogeneity) and blood contamination (colour) in mind. The definition has to be officially finalized by legislators and requirements regarding specificity and sensitivity have to be given. Recommendations for sensitivity and specificity are >80% and >99% (Rasmussen, 2003). The milk inspection technique and separation procedure of the milking system as supplied by the manufacturers have to be evaluated for each system before installation. Rasmussen (2003) proposes a filter method to carry out this evaluation. After installation, the farmer has to monitor both the detection and separation procedures continuously. The farmer must be able to list cows from which the milk is separated.

As teat detection, teat cup attachment, milking and teat cup detachment are completely automated in automatic milking systems, these steps in the milking process have to be monitored continuously both for individual cows and for each milking unit. It is suggested to take off teat cups when milk flow is below a specified level but ultimately after a specified machine on time has elapsed (ISO, 2003). ISO TC 23 suggests that information on teat cup fall off and kick off, correct ending of milking and success of milking are available to the user, and attachment lag time is monitored and checked. Suggested lower and upper limits are 3 and 120 seconds. In conventional systems attachment failures are unlikely. Preferably deviations with a certain significance level are reported automatically. The system must be able to list cows where the last milking was unsuccessful. In case a teat cup is kicked off there has to be a proper intervention procedure, which prevents dirt entering the bulk tank. Dipping or spraying of individual cows should be possible. If cows are dipped or sprayed after teat cup detachment, the level of the agent should be controlled. The farmer can regularly check if the mechanism is functioning as desired.

After each milking a cluster flush has to be performed, and also unit and system flushes are done regularly. The functioning of these flushes, especially the system flushes, has to be monitored. The manufacturer has to indicate checkpoints for visual verification of cleaning (ISO, 2003). The cleaning of the bulk and buffer tanks has to be monitored as well. Quality of water used for cleaning must be as officially required for food safety. Entry of milk in the bulk tank during milk collection and cleaning shall be prevented. The cooling process is usually monitored by an electronic watchdog. The areas in and around the milking unit have to be kept clean separately, which is a responsibility of the farmer.

The farmer must monitor milk cooling. In order to be able to perform milk recording for cows that are milked with an automatic milking system, efficient methods to collect samples are needed as well as mathematical procedures to interpret the data. As milk recording delivers management supporting information, it is possible to manage a dairy farm without official milk recording. With regard to herd replacement there are no specific demands for operational management with automatic milking.

With regard to labour, it is considered important that operational management activities are planned. This not only refers to feeding and checking alert lists, but also to regular cleaning activities, heat detection, health control and other not completely automated controls. This is a responsibility of the farmer. Because automatic milking requires special skills it could be argued that there should be a backup person who is familiar with the automatic milking system and could take care of the farm and manage the herd.

Another demand is that the system is functioning properly, and is robust. At delivery the systems could be tested. Because automatic milking systems need maintenance a good maintenance schedule should be available, addressing both activities a farmer can do himself and activities that have to be done by a professional technician. This includes protocols for dry testing the system. Because of the prominent role of sensors, controlling their functioning should be part of regular service checks but preferably also continuous monitoring should take place. Maintenance should ensure functional integrity, safety and hygiene during the intended lifetime of the systems (ISO, 2003). Time needed for maintenance must be limited in order to maintain system capacity. The manufacturer is primarily responsible to fulfil these demands. From point of view of capacity it is preferred if farmers are able to fix most of the failures themselves, thus limiting idle time. Despite this, the system supplier must be able to deliver quick service in case of breakdowns. Both during the response time (time needed for service technician to reach the farm) and during the problem solving the milking unit is out of order. Even with a reasonable response time of 1-2 hours and 2 hours of problem solving the milking routine is substantially disturbed, especially on farms with a minimum of idle time for their AM system (Sonck, 1996).

Farmers have different ways of managing their farm. Especially with regard to decision support, farmers will have different preferences with regard to sensitivity of alerts. Farmers who use the alerts as information that is additional to their own information probably demand more reliable alerts than farmers who basically rely on the alerts. So the user should have the possibility to adapt some parameters of the software to the own preferences. Because computerized data are of great importance in managing a dairy farm with automatic milking, flexibility both with regard to place and time to access and enter data are demanded. Because the proper functioning of automatic milking units depends on access to the farm database, availability of a backup in case of failures of the management computer is very useful. Thus, a backup procedure for at least the most essential data is necessary. Manufacturers have to provide the flexibilities, farmers have to set parameters according to their needs.

5 Opportunities

Automatic milking enables farmers with health problems to continue dairy farming. Besides the expected reduction of physical labour and enhanced labour flexibility, health concerns are one of the arguments to invest in automatic milking systems (Meskens and Mathijs, 2002). Knappstein (personal comment, 2003) mentioned that farmers with an automatic milking system less often have to handle milk containing substances that can induce allergic reactions, such as penicillin. In areas where it is difficult to hire labour for working on dairy farms the shift of physical activities to supervision might improve the attractivety of farm jobs. Because AM-systems substantially reduce labour requirements (Wauters and Mathijs, 2004) farmers have more time to spend with their families or for their hobbies.

Van Asseldonk (1999) investigated possibilities to improve farm income by technology applications in the situation that the farmer is still available to perform tasks. Some of these applications, such as cow identification and automatic concentrate feeders, are a prerequisite for automatic milking. Automatic milking offers many possibilities to collect data. Potentially these data are useful for decision support, but this requires proper data processing techniques. Van Asseldonk (1999) concluded that automatic measurement of milk yield, milk temperature and conductivity in general was not economically attractive for farms with conventional milking systems. In general, the more skills are required to interpret the information the less of the potential benefits on average are realized in practice.

Total plate count (TPC) on farms in general increases during the first 3 months after introduction of AM-systems, and thereafter stabilizes on a slightly higher level than before introduction (Van der Vorst and Ouweltjes, 2003). Particularly the percentage of bulk tank samples exceeding penalty limits is increased (Van der Vorst et al., 2002). Although it is assumed that system cleaning is by far the most influential factor with regard to TPC, improved control of the teat cleaning procedure could help to further enhance milk quality.

Although visual detection of abnormal milk and clinical mastitis with conventional milking systems is not regarded as problematic (Spahr, 1993), Rasmussen (2003) shows that visual inspection to some extent is subjective. Sensors on the contrary are objective detection aids, and are required for automatic milking where visual detection is impossible. Sensors also allow parameters to be measured that cannot be detected visually. Sensor information could not only be used to detect the onset of diseases, but also to monitor the recovery of the animals. Conductivity sensors and software in conventional parlours were applied with the idea that they could detect sub clinical cases, and in combination with adequate treatment could help to prevent clinical cases to occur. However, treatment of sub clinical mastitis up to now does not seem to be attractive and detection of clinical cases in an early stage has not been possible because of unreliability of the alerts (Hogeveen and Ouweltjes, 2002). Another reason for poor performance of conductivity sensors in conventional parlours were failures of the equipment (De Mol et al., 2001). Wiedemann et al. (2003) argue that, in order to detect mastitis, conductivity should be measured in cisternal milk rather than alveolar milk, and thus improved timing of measurements could result in better mastitis detection. Nielen (1994) concluded that averages of highest readings throughout the complete milking are equally useful, but indeed the highest readings were usually in an early stage of milking. De Mol and Woldt (2001) showed that with improved mathematical procedures and more stable sensors much more reliable alerts can be generated from these averages, this could enable mastitis treatment in early stages.

Software solutions to monitor sensor functioning could help to detect fault sensors. An example is to compare running averages for each conductivity sensor with appropriate means, and unlikely deviations indicate technical problems. Also measurements during cleaning cycles can produce useful information on sensor functioning. Similarly conductivity could be measured during cleaning cycles, and unrealistic values could indicate a problem with the sensor or with cleaning. The possibilities for automatic monitoring of sensors depend on the sensor. With adequate follow up monitoring sensors can improve reliability of alerts. This is particularly important if milk is separated automatically. Modern communication technology could be used to monitor the operation of AMS in general, and sensor functioning in particular by the manufacturer. It can also be useful to improve service and maintenance of AMS.

Another means of improving the reliability of alerts is to use additional sensors, such as measuring milk yield, milk temperature or milk colour for each quarter. This could also be used to refine alerts, resulting in a better indication of what could be wrong. Currently farmers have to combine all available information themselves before they decide on follow up. Possibilities to use sensors to detect metabolic disturbances are discussed by Mottram (1997a), but these are not strictly linked to the milking process. An advantage of application of sensors in automatic milking systems is that less hardware is needed compared to conventional parlours, because there are less milking units. Moreover, automatic milking already has a high degree of automation and all cows are electronically identified.

Sensors that are available in automatic milking units to control milking and monitor cows and milk could also be used to monitor the cleaning process. Besides using these existing sensors additional sensors could be developed specifically to monitor cleaning (Lely, 2003). According to Schuiling et al. (2001) automatically changing the sock filter, which is expected to improve milk quality, is another possible improvement of cleaning procedures in automatic milking units. Sensor supported cleaning of the outside surface of the AMS could also be a possible improvement (Unrath and Kaufmann, 2003).

In general automatic milking enables individual cow management with regard to milking frequency. Wiktorsson et al. (2003) argue that individual settings of management systems might be beneficial for cow health and welfare. For instance cows in early lactation should not be milked with too high frequency, in order to reduce the severity of the negative energy balance (a higher milking frequency stimulates milk production and can result in restricted access to feed). Shortly before drying off a programmed reduction of milking frequency could be applied. Hillerton et al. (2004) however did not find particular benefits of automatic milking for cow health to date. Wiktorsson and Sørensen (2004) point out that herd management influences welfare. Premilking stimulation could be optimized for individual cows, taking for instance milking interval and production level into account (Hogeveen and Ouweltjes, 2003). This could also be a possibility for setting of milking parameters and teat cup detachment. An advantage of automatic milking is that milking and teat cup detachment is possible at quarter level, with potentially beneficial effects on teat end condition (Neijenhuis and Hillerton, 2002). Berglund et al. (2002) did indeed report better teat end quality for cows milked automatically compared to cows milked twice daily with a conventional installation.

Harms and Wendl (2003) have investigated that improvement of teat cup attachment software can enhance system capacity in some existing AM-systems. With regard to attachment of teat cups and separation of milk the chance of misidentification of cows in the milking unit is neglect able, whereas in conventional parlours it can occur that cows are milked at another milking stall than expected by the software. Thus, if the management database is up to date, errors in separating colostrum or milk of treated cows is rather unlikely with automatic milking. Also attaching dry quarters, which can happen in conventional parlours due to man made mistakes, is probably less likely with automatic milking. With conventional milking, without using sensors, only foremilk can be inspected visually. With automatic milking inspection of foremilk is not strictly necessary, because milk can be inspected throughout the whole milking. Theoretically it is possible that foremilk appears normal, but abnormalities appear later on (Rasmussen, 2003). Such abnormalities can also be detected in automatic milking systems, although it is estimated that this phenomenon occurs infrequently. If the decision to separate milk can be taken after a cow is milked, extra information like milk yield can also be used to decide.

Further development of sensor technology, for instance on line or in line fat and protein measurement (Woo et al., 2002), cell counting or progesterone sensing (Pemberton et al., 2001) seems to be particularly promising for automatic milking. Such sensors could further improve the possibilities of management by exception and could help to improve milk quality. Other possibilities like individual feeding, automatic body condition scoring, weighing or breath analysis could enhance this further, but these parameters are not directly linked to milking. Another potential improvement of software is to follow trends at herd or group level more closely, and react appropriately. A significantly lower production could for instance be caused by a failure in concentrate feeding or by an infectious disease that has entered the farm.

6 Current possibilities of available AM systems

Automatic milking does not only depend on AM systems, but also legislation and farmer are important factors. Demands addressed to legislators and farmers are dealt with in chapter 8. From the demands discussed in chapter 4 a list of demands for AM systems is built, the general results are presented in table 2. A distinction is made between data storage and management aspects. In general the data listed are required for herd management and servicing the system, and thus must be accessible for both farmer and service technician. The possibilities of six AM systems of the industrial project partners are presented in appendix 1.

Table 2 Demands and possibilities of currently available AM systems.

Demand	Possibility
Data storage	
Individual milking data	
Cow ID	Available on all systems
Entrance time	Available on all systems
Attachment	Most systems give a score for each milking
Duration	Available on most systems, sometimes on quarter level
Yield	Available on all systems
Teat cleaning success	One system records failures, others don't record this at all
Milking success	Available on all systems
Teat cup fall off	Available on most systems (re-attachment can depend on remaining yield)
Milk destination	Available on some systems
Reason milk diversion	Available on some systems, usually dependent on user settings
Sensor data	Available on all systems, but type of sensors is system dependent
Non milking visits	Available on all systems (cow ID, entrance time)
Machine cleaning data	Most systems record several parameters, none records cleaning results
Alarms	Available on all systems
Management	
Adjustable access criteria	Available on all systems
Interval alarms (cows to fetch)	Fixed on some systems, user adjustable on others
Monitoring capacity performance	All systems give average figures but no warnings
Concentrate allocation	Available on all systems, in and outside of milking unit
Detection of abnormal milk	Usually based on conductivity, no automatic separation
Detection of abnormal animals	Exceptions on a range of parameters are signalled by all systems
Automatic monitoring of sensors	Some systems calibrate sensors automatically
Teat cleaning with result check	All systems perform standardised cleaning procedures, without check
Monitoring milking performance	Some systems only give performance figures, others also give warnings regarding teat detection, attachment and milking
Maintenance guidelines	Available for all systems for both farmers and professionals
Backup of system data	Possible for all systems, sometimes not on separate disk
Handling teat cup fall off	All systems close vacuum and re-attach depending on remaining yield
Spraying individual cows	Some systems can only spray all or no cows, none checks results
Monitored cleaning procedures	Optional for some systems, most just perform standardised procedures
Checklist to control cleaning	Available for all systems (manual checks)
Milk recording	Automatic sampling devices are available for all systems
Flexible parameter settings	Available on all systems, but one has limited flexibility of alarm settings

All manufacturers have developed procedures for intervention in case safety of human, animal or system is at risk and their products do comply with mandatory product safety standards. Also milk entry in the bulk tank during cleaning is prevented in all systems. Furthermore it is assumed that all manufacturers are able to deliver service within an acceptable response time if needed and have educated maintenance personnel so that maintenance time can be limited to about 2 hours. Of course this may not be true everywhere around the world. All manufacturers do provide maintenance guidelines for farmers and service technicians.

The automatic milking units are directly controlled by process software. This software communicates with an additional herd management program. However, systems do usually not automatically set a cow for milk separation after entering a treatment in the herd management software. This has to be done separately. This means that correctly and timely updating this software is very important for milk quality. For one system a special option for introduction of heifers is included. With regard to the database it must be mentioned that for most systems several versions of software are around, with different possibilities. The same holds for hardware, some older versions of robots have less sensors than currently new ones. We have used the most recent system versions to compare demands and possibilities in appendix 1.

Information on milking duration is stored in most systems, in some systems it is stored for each quarter. Most systems detach teat cups one by one, and thus have variable milking duration for quarters. Only one system detaches all teat cups together. The attachment process can only be monitored indirectly in some systems because they count failures or information is only available for servicing, but most systems calculate attachment scores that can be used to evaluate attachment. Information on teat cup fall off or kick off is not recorded by some systems, and thus can not be monitored directly. Some systems record milk destination and reasons for milk diversion, but because milk is currently not separated automatically by any of the systems this represents user defined settings. The results of teat cleaning are not checked automatically by any system, only one system records failures to carry out preset teat cleaning routines. All systems record some parameters of machine cleaning activities, some have optional features to partly monitor system cleaning automatically.

All systems have the possibility to adjust access criteria for individual cows, although for one system cows have to be assigned to one of four groups. Parameters on which these criteria are based are system specific, some use interval or preferred milking frequency, others use expected production or a combination of production and lactation stage. With regard to the interval alarms it can be stated that the criteria to give an alarm are usually fixed, this means that alarms differ in severity of the signalled deviation. Manufacturers also advice farmers not to fetch all cows on the alarm list, but use more information to decide which cows to fetch.

With regard to monitoring capacity performance none of the systems automatically signals possible problems. All systems do report figures on successful milkings, refusals and failures but farmers have to decide themselves whether these figures need follow up. Criteria to classify a milking as a failure differ between systems, some systems have flexible parameters. Active cows, concentrate left overs, or sub optimal parameters are mentioned as possible causes for an increased number of refusals. To monitor milking performance all systems give performance figures, some systems also give warnings. One system reports time spent by the system on different tasks. In one system also the outside of the teat cups is cleaned after milking a cow. None of the systems checks teat cleaning results. For all systems sensors are serviced during professional maintenance turns. Some systems also monitor sensor functioning automatically and have auto calibration procedures. None of the systems is standard equipped with a device to monitor system cleaning, but such a device is available now from one of the manufacturers and could be used for logging data. All manufacturers provide checklists for farmers to control system cleaning manually.

All systems have the possibility to allocate concentrates in the milking box and in separate concentrate feeders. Of course this requires information exchange between the other feeders and the robot system, this may not always be easy especially with equipment from different manufacturers. The fine-tuning is system specific, criteria for alarms for concentrate intake are usually fixed. For one system it is mentioned that calibration of the feeding device deserves attention when other feed is used, but this probably holds for all systems. When teat cup kick off is detected vacuum is closed immediately to prevent sucking of dirt. Apparently all systems re-attach teat cups after fall off, without checking if they are dirty. Some systems do not re-attach if the expected remaining yield is below a threshold. The floor in the milking unit is cleaned automatically in one system to reduce the risk of milk contamination. All systems have the possibility to spray the teats after milking, but for some systems spraying can only be switched on or off for all cows. None of the systems automatically monitors the quality of spraying.

Some systems use the same teat cup for obtaining foremilk and for milking, whereas others combine teat cleaning and premilking with separate teat cups. Current legislation states that foremilk should be inspected before teat cups are attached. Obviously this is the only possibility to inspect foremilk with conventional milking, but it is also assumed that foremilk is of bacteriologically poorer quality than other milk and therefore should not enter the bulk tank. Currently none of the systems automatically separates abnormal milk, although for one system this is technically possible based on quarter milk colour and conductivity. Detection of abnormal milk in all other systems is based on quarter conductivity, but some systems also use conductivity on composite milk. Attention levels are usually fixed but some parameters can be set individually. All systems monitor animal performance based on yield (some systems use quarter yield, most systems use total yield), conductivity (one system only signals increased conductivity, most systems signal all deviations) and milking interval. Most systems also signal low concentrate intake, some mention activity but this is probably optional on all systems. One system monitors milk colour, one system monitors kick off and one system monitors milking speed. None of the systems gives integrated information on abnormalities on animal level, although some systems have the ability to combine alarms in one report. None of the systems separates milk based on a general health check. All systems have facilities to backup data, some do this automatically. For most systems it is possible that backups are stored on the same disk as the original data.

With regard to alarms some systems have the possibility to suppress minor alarms during the night. Also multi user facilities are possible on one system, where alarms can be directed to several users. For some systems the possibility to change parameters for alarms are limited, but in general the users can change system settings to their own preferences.

7 User experiences

In order to get a better idea of how farmers handle the information AM systems can supply, and get input from farmers point of view on possibilities and limitations of the current automatic milking systems, a workshop was held with 10 experienced Dutch dairy farmers working with AM-systems. They indicated that usually the AM system is running unattended between 11 pm and 6 am. Most farmers start their work with going through the screen of cows attended for long milking intervals or milking failures, and usually they also check the alarms for conductivity. They usually do not print attention list, but write down things to be checked in the barn on an action list. Usually only a part of all cows on the lists are fetched, with their experience selecting these cows is not problematic. During the rest of the day the list of cows with long milking intervals is checked another one to three times. Managing milking intervals is their most frequently performed task linked to the AM system, but they also stated that minimizing human interference is important to stimulate cows to come into their own rhythm. The importance of feeding was stressed. At fixed times the teat detection sensor and outer surface of the milking unit are cleaned. It was generally agreed that heat detection is better with automatic milking, activity monitoring can be helpful both to detect heat and to detect abnormalities.

It is noticeable these farmers do not bother too much about false positive (FP) alarms, but none of these farmers currently separates abnormal milk automatically. Mastitis detection is not solely based on conductivity, at least milk yield and interval are also taken into account. They do not regard it as problematic that thus truly abnormal milk could be milked into the bulk tank. However, one of them intends to separate automatically based on colour, because he once had to discard bulk milk because it was reddish due to blood. These farmers are more bothered by false negative cases. But this has to do with the way they handle alerts: first they combine available information, not only from the AMS but also lactation days, days to calving and cell counts. Combining the information manually is acceptable for them, they do not feel a need for integrated alarms. In general they indicated they are satisfied with the current possibilities of their AM systems, although it is mentioned that the same information does appear on several attention lists. It is also remarkable that all farmers had their own preferences of how to use information to manage the farm. Flexibility of software in this regard therefore is a must.

Usually the systems are installed with both primary robot process software and an additional herd management program. Dutch farmers have indicated they often use other management programs for total farm management, and integration of these programs and software installed with the robot is poor because standards to exchange information are not well worked out. Therefore correctly entering events such as calving or treatment with antibiotics takes several steps and requires some experience with the software. This does increase the risk of failures in separating milk, although a well defined protocol for handling mastitis cases can help to reduce failures. For some systems data have to be exchanged before reports are made, because otherwise recent information could be missed. Because farmers combine available information from both herd management programs and AMS software to judge alarms, but also because of ease of working etc. they would appreciate a better communication between the AMS software and the farm management program. This is also important with regard to be able to hire relief milkers. Currently working with AM systems not only requires affinity with automation, but also experience with these systems and knowing the animals.

8 Concluding remarks

Some demands are addressed to legislators, and therefore can not be linked to currently existing systems. However, the following demands have to be fulfilled in order to give the manufacturers the possibility to comply with regulation:

- define unacceptable health status in such a way that both automatic unattended milking and conventional milking are possible and give requirements for sensitivity and specificity
- define abnormal milk in such a way that both automatic unattended milking and conventional milking are possible and give requirements for sensitivity and specificity
- describe standardised test procedures for equipment to detect abnormalities

In general double standards should be avoided. Regulation regarding udder and teat inspection is also not yet completed. If teat cleaning is to be evaluated manually it should be stated how. According to Chalus (2002) new EU legislation is on its way.

Furthermore some demands are addressed to farmers, these are also not directly linked to existing systems. Affinity with automation and management by exception are characteristics that can be fulfilled. Farmers also have to set variable parameters according to their own needs, use them correctly and give adequate follow up. They have to work with secure schedules, for instance first enter treatment data in the computer (also activating milk separation) and then treat sic cows (maybe a handheld terminal could be helpful) and respond as should on alarms for system and animals. Data must be exchanged immediately between the robot process software and the management program used by the farmer. In order to prevent cleaning failures farmers have to maintain clean udders and teats and monitor teat cleaning. They are also responsible for updating the robot software with necessary information on undesired and contaminated milk (to be separated) and have to monitor the functioning of the system. Cleaning of the system and bulk tanks also should be monitored by the farmer, they are also responsible for cleaning the area in and around the milking unit regularly. Wauters and Mathijs (2004) suggest that part of the labour time that can be saved with AM-systems is used to improve farm management.

As described in chapter 6, not all of the demands for automatic milking are yet fulfilled by the current systems. Despite this farmers using these systems in general are satisfied with the current possibilities and do not have a clear view which further improvements are possible. Demands that are currently least fulfilled by the existing systems are listed in table 3, the overall list is given in chapter 6.

Table 3 Unfulfilled demands for AM systems

Automatic separation of abnormal milk and milk from cows with unacceptable health
Automatically controlled teat cleaning
Automatically controlled system cleaning
Automatic detection of possible capacity problems
Automatic detection of possible milking problems

Because of growing importance of food quality and food safety it is considered unacceptable in the long run if abnormal milk or milk from visibly unhealthy animals is milked into the bulk tank, especially if possibilities exist to prevent this. As indicated, this first of all requires adaptation of legislation. Because even with conventional milking a 100% guarantee is impossible, realistic standards have to be set for automatic milking, so that when fulfilling these standards food safety is similar for automatic milking and conventional milking. Specificity of sensors and software that are currently used is considered too low to enable automatic separation of abnormal milk, although with a low sensitivity it could be realistic.

Severely abnormal sensor readings could be used for separation, whereas moderate deviations could be used for alarms only. Improvement of existing sensors and software is possible, but probably more promising is the use of additional sensors. Especially sensors that measure signals that are close to visual observation could reduce the number of false positive alarms, as long as visual observation is the gold standard. In this regard colour or homogeneity are to be preferred above conductivity. With more complex sensor systems the need for integrated analysis and diagnosis will increase.

Although the automatic milking systems usually give average performance figures, the interpretation of these figures is usually left to the farmers. As with figures on individual cows management by exception seems possible, thus the attention of the farmer can be focussed where it is really needed. Automated control of teat and system cleaning can further reduce the risk of milk quality problems due to improper cleaning. It could also be used to enhance system capacity, because cows with clean teats could be cleaned less intense than cows with dirty teats.

Besides some unfulfilled demands, automatic milking also does have opportunities if it is compared to conventional milking. Apart from economic perspectives resulting from further technological improvement, and enabling people with health problems to continue dairy farming, it potentially also enhances food safety and food quality. This is because the role of humans in the production chain is diminished compared to conventional milking. Humans remain the weakest factor in quality management, and sensors have the potential to register more than can be observed visually. The original idea to apply sensors to be able to detect abnormalities in an early stage could also become reality, but this requires more reliable parameters than currently available and well defined protocols for treatment. For this purpose sensors that measure invisible physiological parameters are more appropriate than visual parameters. For automatic milking systems this however is not a demand but it certainly is a possibility. If this is realised, automatic milking could also become beneficial with regard to animal health. Constantly monitoring and calibrating the equipment will become routine. Although automatic separation will become reality, it still remains necessary that the farmer be informed about abnormalities and checks what is to be done with the cow.

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Appendix 1 Demands and possibilities of currently existing AM systems*

	AM system number					
Demand	1	2	3	4	5	6
Individual milking data						
Cow ID	Yes	Yes	Yes	Yes	Yes	Yes
Entrance time	Yes	Yes	Yes	Yes	Yes	Yes
Attachment score	Yes[1]	Yes	No	Yes	No[2]	Yes
Duration	Yes	Yes	No	Yes	Yes	Yes
Yield	Yes	Yes	Yes	Yes	Yes	Yes
Teat cleaning success	Failures	No	No	No	No	No
Milking success	Yes	Yes	Yes	Yes	Yes	Yes
Teat cup fall off	Yes	Yes	?	Yes	?	Yes
Milk destination	Yes	Yes	No	No	Yes	No
Reason milk diversion	Yes	Yes	No	No	Yes	Yes[3]
Sensor data	Yes	Yes	Yes	Yes	Yes	Yes
Non milking visits	Yes	Yes	Yes	Yes	Yes	Yes
Machine cleaning data (start time, duration, action, success y/n)	Yes	Yes[4]	No	Yes[5]	Yes[6]	Yes[7]
Alarms	Yes	Yes	Yes	Yes	Yes	Yes
Management						
Adjustable access criteria	Yes	Yes	Yes	Yes	Yes	Yes
Interval alarms (cows to fetch)	Yes	Yes	Yes	Yes	Yes	Yes
Monitoring capacity performance[8]	Yes	Yes	Yes	Yes	Yes	Yes
Concentrate allocation	Yes	Yes	Yes	Yes	Yes	Yes
Detection of abnormal milk	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[10]	Yes[9]
Detection of abnormal animals	Yes	Yes	Yes	Yes	Yes	Yes
Automatic monitoring of sensors	Yes	Yes[11]	No	No	No	No
Teat cleaning with result check	No	No	No	No	No	No
Monitoring milking performance	Yes[12]	Yes	No	Yes[13]	Yes[13]	Yes
Maintenance guidelines	Yes	Yes		Yes	Yes	Yes
Backup of system data	Yes	Yes[14]		Yes[15]	Yes	Yes
Handling teat cup fall off[16]	Yes	Yes	Yes	Yes	Yes	Yes
Spraying individual cows[17]	Yes	Yes	No	No	Yes	Yes
Monitored cleaning procedures	Yes	No	No	No	Option	Option
Checklist to control cleaning	Yes	Yes	Yes	Yes	Yes	Yes
Milk recording	Yes	Yes	Yes	Yes	Yes	Yes
Flexible parameter settings	Yes	Yes		Yes	Yes[18]	Yes

* manufactured by the industrial partners of EU-project QLK5-2000-31006

1 data only available for service purposes
2 attachment failures are recorded
3 for colostrum
4 number of cleanings performed
5 temperature, starting time, detergent
6 time spent and optionally more
7 time only
8 Average figures given, no warnings
9 Based on conductivity, no automatic separation
10 Based on conductivity and colour, automatic separation possible but mostly unused
11 Auto calibration of conductivity
12 Some figures only available for service purposes
13 Performance figures but no warnings
14 Automatically
15 Backup on same disk is possible
16 Closing vacuum immediately and re-attach dependent on remaining expected yield
17 If yes then spraying can be set for each cow, if no than spraying can only be set on or off for all cows. None of the systems checks the results
18 Parameters to trigger alarms usually can not be set