The evolving world of precision dairy technology – Part II

Marcia I. Endres, DVM, MS, PhD
University of Minnesota, 1364 Eckles Avenue, St. Paul, MN 55108, miendres@umn.edu

Abstract

An area within precision dairy farming is automation for milking and feeding cattle. Robotic milking systems are becoming more common worldwide, with rapid growth taking place throughout the USA. In addition, more farms are installing computerized automated feeders that can feed whole milk, milk replacer, or combinations of whole milk and milk replacer to individual calves in a controlled manner according to a predefined feeding plan. This automation technology also commonly provides individual animal data that can be used to more precisely manage the herd. Various aspects related to housing and management are critical for the success of these technologies on the dairy farm such as sanitation, feeding practices, animal training, barn design, animal grouping, animal health monitoring, and equipment maintenance.

Key words: robotic milking, automated milk feeder, dairy automation, dairy technology

Résumé

L'agriculture de précision à la ferme laitière inclut l'automatisation de la traite et de l'alimentation du bétail. Les systèmes de traite robotisée sont de plus en plus fréquent à travers le monde et sont en pleine croissance partout aux États-Unis. Plus de fermes instaurent aussi des alimentateurs automatisés et informatisés qui peuvent fournir du lait entier, du lait de remplacement ou une combinaison de lait entier et de lait de remplacement individuellement à des veaux de façon contrôlée suivant un plan de distribution prédéfini. Cette technologie automatisée fournit couramment des données individuelles sur des animaux qui peuvent être utilisées pour gérer le troupeau avec plus de précision. Plusieurs facettes associées au logement et à la régie sont cruciales pour le succès de ces technologies à la ferme laitière. Elles incluent le nettoyage, les pratiques d'alimentation, le dressage des animaux, la conception de l'étable, le regroupement des animaux, la surveillance de la santé animale et l'entretien de l'équipement.

Introduction

Part I of the review on precision dairy technology focused on the monitoring of individual animals using sensors along with integration of data for decision making. Another area within precision dairy is automation for milking and feeding cattle. This automation technology also commonly provides individual animal data that can be used to more precisely manage the herd.

Robotic milking systems (**RMS**) are becoming more common worldwide, with rapid growth taking place throughout the USA. It is estimated that there are ~25,000 RMS farms in the world.[30] Preweaned dairy calves can be housed individually or in groups. Most farms in the USA house calves individually[38] (69.7% of the farms). However, a combination of animal, societal, and economic factors have most likely contributed to a recent increase in the number of dairy farms considering group housing as an option for preweaned calves; therefore, use of automated milk feeders is also growing rapidly in North America.[24]

Robotic Milking Systems

The milking process is well suited for robotic technology. It is a repetitive process where the teats are found and cleaned, abnormal milk identified, cows milked and post-dipped. A robotic arm prepares the teats for milking and attaches the milking units. Lasers, cameras or combinations are used to find the teats. Teat cleaning is done by automatic brushes or prepping cups. After milking, teats are automatically sprayed with disinfectant or disinfectant is applied by using the cup. Surveys indicate that the most common reasons dairy farmers install RMS are lifestyle, labor management, and human health issues.[10,33]

The majority of robotic milking systems in the world today are single-box systems with 1 robotic arm per milking unit. Cows voluntarily visit the robot box for milking. A smaller number of rotary RMS are in operation in Europe, Canada, Australia, and the USA, and these systems usually utilize a more conventional way of milking cows, i.e., cows are moved to the milking parlor in groups by a worker and are batch-milked 2 or 3 times per day.

One of the advantages of RMS is that they provide a consistent milking routine with no need to train workers. It is also becoming more difficult to find employees that are willing to manually milk cows. Another advantage of RMS is that they automatically collect large amounts of data on each individual cow on a daily basis. If used by the dairy farmer, this information can greatly assist with management of the herd.

A recent review of the literature[19] on detection of health disorders using data from RMS and associated technologies reported consistent trends in activity, rumination time, and milk production changes prior to diagnosis. Authors suggested that more work is still needed to incorporate validated algorithms and models for more accurate health alerts. In

addition, integration of data is needed to support decision making at the farm.

There are disadvantages of RMS. Capital investment is currently higher per cow than other milking systems. The technology is rapidly evolving, so obsolescence of an expensive capital investment is a concern, along with expected higher repair and maintenance costs than conventional milking systems.

Factors positively associated with milk production per RMS in 32 free-flow farms in Minnesota and Wisconsin included number of milking visits to the RMS box per day, cow milking speed, number of cows per RMS, average age of the cows in the herd, and daily amount of robot feed offered in the RMS per cow.[31] Conversely, factors that were negatively associated with milk per RMS included residual feed (feed programmed to be offered to the cow, but not consumed), treatment time (the time spent preparing the udder before milking and applying a teat disinfectant after milking), failed visits (visits where the cow had permission to be milked but the milking unit could not attach or she did not complete the milking), and refused visits (cows visited the milking box, but milking permissions did not allow her to be milked).

Barn Design Considerations

The design of the RMS barn should encourage natural cow movement that results in frequent visits to the milking box and minimizes labor. This can be accomplished by building a new facility where RMS is installed or by retrofitting an older facility. Research has shown no differences in milk production between new and retrofitted RMS barns.[31,35]

There are 2 types of cow traffic in RMS – free-flow and guided-flow. In barns with free-flow traffic, cows can access all areas of the barn without restriction. In guided-flow traffic, 1-way gates and selection gates are used to guide cows to milking, feeding, and resting areas.

The 2 types of guided-flow traffic are milk first and feed first. In the milk-first system, cows leaving the resting area must pass through a pre-selection gate that determines if they are eligible for milking. If a cow meets the requirement to be milked, she is guided to a commitment pen that contains the RMS box. If she is not eligible for milking, she is allowed to enter the feeding area and can only re-enter the resting area through a 1-way gate. Pre-selection gates can also be installed in crossovers away from the RMS box and open only for cows not eligible for milking.

In the feed-first system, cow traffic is the reversal of the milk-first system. After eating, cows enter a selection gate that determines if they are eligible for milking. The gate either guides her to the commitment pen for milking or to the resting area. The commitment pen is a gated area next to the RMS box that cows eligible for milking cannot leave until they are milked.

Both free-flow and guided-flow systems can be successful. In general, research has shown that there are fewer fetch cows with guided-flow systems than free-flow systems.[2] Fetch cows are those cows that need to be brought to the RMS

by a worker, as they did not visit the RMS box voluntarily within a period of time based on milking permission settings. Free-flow traffic was associated with greater milk production per cow per day[35] compared to guided flow. Cows in a guided-flow system consumed less meals per day, but larger meals with longer meal duration when they visited the feed bunk, resulting in no difference in total eating time, eating rate, or average daily dry matter intake compared to free-flow.[2]

In robotic milking system barns, lactating cows stay in their home pen and are not moved to a parlor for milking. This makes tasks such as bedding stalls and scraping manure more challenging as cows are in the pen at all times. Research on specific aspects of barn design that improve labor efficiency and cow comfort is very limited. It has been recommended [30] that manual scraping of manure is not ideal, as it causes more disruption to the cows. Automated systems are more favorable. In addition, layouts with wide alleys, free traffic, and many crossovers will offer more escape routes for cows when equipment enters the barn.

It is also recommended that devices such as cow brushes be installed away from the RMS box to entice cows not eligible for milking to move away, and to have a protected exit lane at least 1 cow-length long at the exit of the RMS box.[30] In addition, the area around the RMS should be free of stray voltage. Rubber flooring should be installed in the RMS box along with cooling fans over the cows as they are milked. It is important to make the RMS box attractive to the cows to increase milking visits.

Fetching cows has to be as simple as possible, with least disruption, and 1 person should be able to accomplish this task without additional help. The use of a split-entry fetch pen that holds 4 to 5 cows at a time in free-flow systems can be helpful.[30] This pen does not have access to water, feed, or freestalls and it is used only for fetched cows to access the RMS box by a free-swinging gate at the entry to the RMS box. Other cows in the pen still have access to the RMS box from the other side of the gate. He suggests that this option provides some protection for more submissive cows. Research in the Netherlands[9] indicated that the use of a split-entry fetch pen could improve milk production per robot.

A sort pen for cows that need to be handled for breeding, treatment, or hoof care is also recommended.[30] This pen needs to include resting space and access to feed and water, and the opportunity to return for milking. Housing fresh, lame or injured cows in a bedded pack near the RMS box with robot access could be beneficial.[30] The presence of a straw bedded pack near the RMS box was associated with greater milk production per RMS.[9] It is also suggested that RMS barns might work better with perimeter feeding.[30]

Feeding Management in RMS Farms

One of the most important factors to success in RMS is how cows are fed. This review article focuses on box robots, not the fully automated rotary parlors where cows are fed similarly to a conventional parlor herd. In box RMS herds, a

partial mixed ration (PMR), containing all of the forage and a portion of the concentrate, is offered in the feed bunk. An additional amount of concentrate is fed in the RMS box; this amount varies according to the cow's stage of lactation and/or milk production.

The major motivating factor to attract cows to consistently visit the RMS box is the pelleted concentrate that is offered in the box.[29] However, cows' visits to the RMS box are not only dependent on the PMR delivered in the feed bunk and pellets offered in the RMS, but also on feeding management, cow comfort, cow health, and social interactions among cows. Heat stress can result in reduced feed intake and decreased number of visits to the RMS box. Severely lame cows are also less likely to visit the RMS box voluntarily.[2] These factors need to be considered in a feeding program for RMS herds.

Providing a high-energy PMR and limiting the quantity of concentrate pellet in the RMS box to approximately 1 lb (0.45 kg) per cow per day improved overall daily dry matter intake, increased PMR eating rate and meal size, and reduced sorting of the PMR as compared to feeding a low-energy PMR along with 11 lb (5 kg) per cow per day of concentrate pellet in the RMS box[8]. For every 1 lb increase in concentrate offered in the RMS, there was a 1.58 lb reduction in PMR intake. There was no significant difference in milk production between treatments. The study was conducted on a farm with a feed first guided-flow RMS. In contrast, the amount of concentrate offered in the RMS was positively associated with milk production per cow and per RMS in a study with free-flow RMS farms in the USA.[31]

It has been suggested[3] that concentrate meal sizes be limited to approximately 3.5 lb (1.5 kg) or less per visit so that cows consume all the feed that is allocated to them at each visit, and total daily concentrate offered in the RMS be limited to approximately 9 lb (4 kg) per cow. However, more research is needed to conclusively determine amounts of concentrate to be fed in the RMS, and this might be highly dependent on type of cow traffic flow.

When RMS is used in grazing herds, there is an additional challenge of enticing cows to leave the pasture and voluntarily attend the RMS box. In pasture-based systems there appears to be a relatively large percentage of cows with long milking intervals (defined as greater than 16 hours). A study[22] in Australia found that 47 and 38% of milking intervals exceeded the 16-hour threshold in groups of cows fed a PMR and concentrate pre- and post-milking, respectively. A longer distance (850 feet [260 m]) to pasture from the RMS box resulted in reduced daily milk yield (58.2 vs 64.1 lb [26.4 vs 29.1 kg]) and milking frequency (2.3 vs 2.5 milkings/day) than a shorter distance (164 feet [50 m])[32]. Milking intervals were longer when the distance from the RMS box was greater than 1650 feet (500 m).[23]

Fresh Cow Management

Cows visit a RMS box voluntarily to be milked, starting in most cases immediately after calving. A few farms milk their cows in a separate location for the first 2 to 5 days-in-milk (DIM). Most RMS producers will pay closer attention to fresh cows and ensure that they are visiting the RMS box consistently and often. Separation of fresh cows can be beneficial, as these animals are most likely less dominant in the hierarchy scale; however, no research has been published to test this hypothesis. A simulation model[7] developed using observations from 15,000 milkings in a RMS herd in Israel showed that on a normal day a low-ranking cow waited 68.9 minutes in line to be milked in the RMS, compared to only 10 minutes for a middle-ranking cow and 3.5 minutes for a high-ranking cow. On a crowded day, because RMS had been stopped or blocked for a longer period of time, a middle-ranking cow waited for 93.5 minutes, whereas a low-ranking cow waited for 412 minutes.

Better training of fresh cows to use the RMS, especially primiparous cows, could potentially improve productivity of RMS farms. Most farms fetch their fresh cows for a few days in the beginning of lactation to ensure they are visiting the RMS. The use of automated concentrate feeders in the pre-fresh pen is becoming more common. This helps cows become more acquainted with an automated system and more likely to voluntarily visit the RMS in early lactation.

A case study[27] on a RMS farm that trained heifers during the pre-fresh period compared milking frequency of primiparous cows before and after the training was implemented. Heifers were housed in a bedded pack pen within the RMS barn and physically brought through the RMS box twice a day, where they were offered 1 lb (0.45 kg) of concentrate pellet per visit. Milking frequency (milking visits per day) of primiparous cows for the year before they started their training protocol and the year after training was approximately 1.2 visits per day greater in early lactation for trained cows. It is important to point out that this farm had enough free time available in the RMS to do the training. This approach might not be feasible if the RMS is being used to full capacity (suggested by manufacturers to be 60 to 65 cows per RMS box in free-flow RMS).

As previously mentioned, one of the advantages of RMS is the amount of individual cow data collected every day. All RMS software will record milk yield per cow at each visit and daily. Other measurements include (some are optional): milk fat, protein and lactose percent, milk color, milk temperature, milk conductivity, milk SCC (not yet in the USA as of this writing), cow rumination time and activity, cow body weight, intake of RMS concentrate feed, number and type (milking, refused, failed) of RMS visits per day, pre-milk and milking time per visit, and average box time per day. Combinations of these measurements can be very helpful to detect potentially sick cows; RMS companies have been developing various proprietary algorithms to create daily action lists for cows needing attention. Technology helps producers manage their cows but will not replace a human caretaker.

Change in cow body weight in early lactation could also have potential to help identify cows at risk during the transi-

tion period. A study in New York state[5] investigated the relationship between subclinical hypocalcemia and body weight change during the first 30 DIM for cows on 3 RMS farms. All cows lost weight in the first 30 DIM. However, primiparous cows with disease (and normocalcemia) lost the most weight within the primiparous cohort. Cows within second lactation with both disease and negative energy balance (and normocalcemia) lost the most weight. Cows in third lactation or greater with subclinical hypocalcemia and either disease or negative energy balance lost the most weight within the older cow cohort.

Another important aspect to monitor in RMS farms is lameness prevalence, not only during the transition period but throughout lactation. Research has shown that lame cows visit the RMS box less often and need to be fetched more or have lower milk production[1, 18] than non-lame cows. This could be especially problematic during the transition period and in early lactation.

Changes in body weight and milk production along with rumination and activity can help manage transition cows. In reality, as mentioned previously, producers rely on summaries provided by the RMS software that combine various measurements to create a health report. Not much research has been conducted focusing on the transition period in RMS herds, and more research is warranted in order to further improve management of transition cows in RMS. The following practices may increase the likelihood that all cows have a successful transition and high milk production:

- Use of multiple feeds through the milking station which allows the producer to use feed additives specifically targeted to fresh cows.
- Special observation and monitoring of fresh cows. Fresh cows that are not feeling well may continue to consume all the RMS box pellet but decrease intake of the PMR at the feed bunk. This can potentially lead to subacute ruminal acidosis, digestive upsets, and increase the risk for other diseases.
- Observation of rumination and activity on all fresh cows daily. The RMS software (depending on the system) can create a daily list of cows that are not meeting rumination and activity goals or had a recent change from their baseline values.
- Feeding a high quality PMR to encourage intake at the feed bunk.
- Adequate fetching of fresh cows.

The RMS will most likely continue to improve and provide additional precision individual cow measurements that help improve cow health and management. However, daily cow observation is still very important and crucial for a successful transition and optimal health and productivity of an RMS herd.

Milk Quality and Udder Health in RMS Farms

One area that can be challenging to manage in RMS is udder health. A review of epidemiological studies indicated that udder health was compromised after introduction of RMS[11]. In contrast, a recent survey in Canada[36] showed that change in bulk tank SCC varied across farms when transitioning from conventional milking to RMS, with 43%, 37%, and 20% of respondents indicating a decrease, no change, or increase, respectively. The geometric mean SCC was 180,000 cells/mL.

Producers depend on the RMS detection tools to identify mastitis cases and divert the milk from the bulk tank since workers are not evaluating the fore milk in the parlor like in a conventional system. One of the advantages in RMS is that quarters are individually milked and detached, which reduces overmilking. There is also less risk for antibiotic contamination with a treated cow, as long as her ID is entered in the computer correctly and the milk is discarded.

Electrical conductivity of the milk is one of the parameters used to help detect mastitis cases in RMS. Previous review of the literature[11] indicated that electrical conductivity is an inadequate method to detect subclinical or clinical mastitis, and abnormal milk in general. However, most RMS will include additional measurements. A clinical mastitis detection model including electrical conductivity, milk color, dead milk time, and milk yield proportion per quarter[37] achieved a sensitivity and specificity of 88.9% and 99.3%, respectively, when combined with defined variables (a clinical mastitis time window of 5 days and including 3 previous milkings).

One current weakness with RMS (depending on the system) is teat preparation for milking and post-dipping. A review of the literature[11] reported that 8% of teat cleanings per cow failed due to machine problems and 4% because of cow-related problems, including kick-offs. One of the studies mentioned in the review found that only 67% of the cleanings were technically successful, i.e., all 4 teats were brushed. In the best performing farm, over 95% of the teat cleanings were technically successful. Reasons for most of the failed teat cleanings were undetermined but of the known causes, a device failure in 1 herd and restless behavior of the cows in several herds were associated with most of the totally unsuccessful teat cleanings, whereas abnormal udder and teat structure were associated with most of the partly unsuccessful teat cleanings.

It is important that cows visit the RMS box on a regular basis. If cows have a very long milking interval, leaking of milk greatly increases and these cows are at higher risk for mastitis. A case-control study using data from a 1,549-cow RMS farm with 20 boxes[28] showed an increased risk of quarter clinical mastitis with increasing milking interval.

Keeping the barn and stalls clean is very critical; the RMS cannot distinguish between dirty and clean udders, therefore it is important that cows enter the RMS unit with a lower bacteria load. The annual average herd SCC in RMS herds was positively associated with the proportion of cows with dirty teats before milking and the proportion of cows with dirty legs.[6] In addition, the annual average percentage of new cows with high SCC was positively associated with

the proportion of cows with dirty teats before milking. At the cow level, hygiene scores of the udder, thighs, and legs were positively associated with SCC.

Automated Milk Feeders

Computerized automated feeders can feed whole milk, milk replacer, or combinations of whole milk and milk replacer to individual calves in a controlled manner according to a predefined feeding plan. Calves are housed in a group and identified using radio frequency identification tags. The milk quantity is dispensed by the automated feeder over several feedings per day. The computer records important data relating to animals' feeding behavior to supplement the daily visual monitoring and to keep records on how much milk or milk replacer is delivered per calf.

Dairy producers might be interested in purchasing automated calf feeders partly because of labor savings or more flexibility of labor; however, the ability to feed calves multiple times a day is also an advantage. Automated feeders can distribute the total daily milk intake into smaller meals throughout the day, with no extra labor necessary. A greater amount of milk can be fed daily than in individual housing without requiring the calf to drink a very large amount of milk at a time.

Calves are typically introduced to the feeder and group housing at 1 to 14 days of age. The average age at introduction to the autofeeder group in 38 farms of the Upper Midwest USA was 5.4 days;[17] 25% of producers were introducing calves at day 1. More training by the caretaker was needed when introducing calves at day 1 compared to day 5 of age.[26] Calves introduced to an autofeeder group (median group size 18 calves) at 6 days of age had more difficulty in getting access to the feeder during the first days after introduction in this dynamic group and required more training from the caretaker.[13] Successful introduction to the feeder at a younger age is likely dependent on calf vigor and passive immunity. Disease risk was similar between calves introduced at day 1 compared to day 5 of age; however, the risk of severe vs mild diarrhea was greater for early- compared with later-introduced calves (odds ratio = 4.7; 95% CI 1.01 to 31.1).[26] In a longitudinal observational study of 38 farms with automated feeders,[15] no association was found between age of introduction and health scores; other management factors might have had greater influence on the success of using feeders in that study.

Risk Factors for Calf Disease and Mortality when Using Automated Feeders

The association between calf health and various housing and management factors was investigated in a longitudinal study involving 38 farms in the USA.[15] Farms were visited every 2 months for 18 months. A total of 10,179 calves were scored over the study period by a single observer for attitude, ear, eye, and nasal health, as well as evidence of diarrhea (hide dirtiness score of perianal region, underside of the tail, and tailhead). Milk standard bacterial plate count (SPC) greater than 100,000 cells per mL was associated with abnormal health scores. Provision of high quality, clean milk to calves is very critical. The median SPC for the top 10 farms in the study was 87,590 cells per mL, whereas for the bottom 10 farms the median SPC was 21,141,000 cells per mL. This is a large difference and can help explain success versus failure when using automated feeding systems. In addition, farms that waited longer to provide the peak milk allowance to their calves had worse health scores. Most farms increased the amount of milk incrementally rather than offering a large amount of milk from day one. This probably is a good management practice, but the study indicated that it might be better to achieve the peak amount in a shorter number of days. Average number of days to reach peak allowance was 18 days. Space per calf was associated with abnormal health scores independent of group size. This would be an important consideration when determining pen size. Average space per calf was 49 ft² (4.6 m²). Barns that did not have a positive pressure ventilation system in use were associated with an 80.6% increase in the likelihood of a calf being diagnosed with fever. Another factor associated with health scores was group size. A study in Denmark[12] showed higher competition to access the autofeeder in groups with 24 calves compared to groups with 12 calves. The same study also suggested that it was better to provide the same milk allowance in 4 rather than 8 meals per day to reduce competition for access to the feeder.

A study with 17 automated milk feeder farms in Canada[25] found that the overall calf-level prevalence of diarrhea and respiratory disease were 23 and 17%, respectively. Median (interquartile range, IQR) within-pen prevalence of diarrhea and respiratory disease were 17% (7 to 37%) and 11% (0 to 28%), respectively. Administration of vitamin E and selenium at birth (odds ratio [OR] = 0.56; 95% confidence interval [CI]: 0.32 to 0.99), feeding of probiotics (OR = 0.44, 95% CI: 0.22 to 0.93), and adding fresh bedding every 2 to 3 days (OR = 0.43; 95% CI: 0.24 to 0.76) compared with every 7 or more days were all associated with lower within-pen prevalence of diarrhea. In contrast, sharing air with older cattle (>9 months old) was associated with increased within-pen prevalence of diarrhea (OR = 4.54, 95% CI: 1.88 to 10.52). In addition, total bacteria count ≥100,000 cfu/mL in milk samples from the automated feeder mixing jar was associated with increased within-pen prevalence of diarrhea during the summer visit (OR = 3.34; 95% CI: 1.31 to 8.54). Greater percent of total solids in milk or milk replacer (OR = 0.48, 95% CI: 0.27 to 0.85) and feeding whole milk vs milk replacer (OR = 0.29, 95% CI: 0.11 to 0.75) were associated with lower within-pen prevalence of respiratory disease. Sharing air with weaned cattle (OR = 3.21, 95% CI: 1.26 to 8.16) and a wet bedding pack were associated with greater within-pen prevalence of respiratory disease. Using maternity pens for other than just calving was associated with increased prevalence of both diarrhea and respiratory

disease (OR = 1.85, 95% CI: 1.03 to 3.33; OR = 2.61, 95% CI: 1.21 to 5.58, respectively). Authors suggested that isolation from older animals and frequent cleaning of the automated feeder and the group pen may help to reduce disease prevalence in group-housed calves.

Mortality rates in a study with 26 automated feeder farms in the USA[16] were associated with navel disinfection. Farms that disinfected the navels of newborn calves had lower mortality rate (mean = 3.0%; standard error = 0.8; 78% of farms) than farms that did not disinfect (mean = 7.3%; standard error = 1.6; 22% of farms). In addition, herd size (number of cows on site) was negatively associated (correlation coefficient [r] = −0.53), whereas the age range in calf groups was positively associated (r = 0.58) with mortality rate. Average serum total protein concentration tended to be negatively associated with annual mortality rate (r = −0.39; median = 5.4; range = 5.0–6.4 g/dL). The median annual mortality rate in the study was 2.6 % (interquartile range = 3.6; range = 0.24–13.4). Treatment rate was positively associated with coliform bacterial count in automated feeder hose milk samples (r = 0.45; mean ± standard deviation [SD] = 6.45 ± 4.50 ln [cfu/mL]) and the age of calves at grouping (r = 0.50; mean ± SD = 5.1 ± 3.6 d).

Monitoring Health in Automated Feeder Farms

Housing preweaned calves in groups can present some challenges to calf health; observation of individual calves is more difficult and the spread of pathogens more likely. The feeding behavior data collected by the automated feeder software is commonly used to generate a daily warning for calves that might potentially be sick or need special attention. The software records number and timing of visits to the nipple station, amount of milk consumed at each visit, drinking speed, and the number of rewarded (milk is fed) and unrewarded (when no milk is fed) visits. The user can usually select what warning measurements to include, but most commonly, daily consumption and sometimes drinking speed are included in the alarm settings.

The relationship between health treatment records (as a measure of morbidity) and calf feeding behavior around the period of sickness detection was investigated in a prospective observational cohort study with 10 farms.[20] Morbidity and mortality events were recorded by farm personnel. Differences in daily average feeding behaviors collected by the automated feeder software (drinking speed, daily consumption, rewarded visits, unrewarded visits) between matched sick and healthy calves around the time of an illness event (−10 to 10 days) were analyzed. Fifty-five percent of sick calves in the study were treated for diarrhea, 30% were treated for pneumonia, and 15% were treated for ill thrift. Sick calves drank 183 ± 27 mL/min more slowly, drank 1.2 ± 0.6 L/d less milk, and had 3.1 ± 0.7 fewer unrewarded visits than healthy calves on the first day of treatment. These differences were detected up to 4 days before the calf was detected as sick by the caretaker. Rewarded visits were not associated with morbidity.

A study in Canada[4] showed that sick calves fed high allowances of milk or milk replacer (≥ 12 L/day) reduced daily milk consumption (−2.59 ± 0.7 L) and number of visits to the autofeeder (−2.43 ± 0.3 visits), and increased the time spent at each visit to the feeder (1.66 ± 0.5 min) compared with healthy calves fed at the same allowance. However, sick calves fed a low allowance of milk or milk replacer (4 L/day) only decreased the time spent at each visit to the feeder (−1.35 ± 0.2 min/visit) compared with healthy calves. Their results indicate that milk allowance can affect calf feeding behavior associated with disease in preweaned calves.

A study in Europe[34] showed that the number of unrewarded visits was more sensitive to detect disease than milk consumption, drinking speed or number of rewarded visits. However, it is important to note that the calf feeding program used on the farm may also affect the number of unrewarded visits. A study in Denmark[14] showed that calves on high milk allowance (9.6 L/d for Holsteins) had less unrewarded visits to the automated feeder than calves on low milk allowance (4.8 L/d). It was suggested that the low milk allowance calves had more unrewarded visits because they were still hungry and visited the feeder more often looking for more milk. Single and combinations of statistical process control signals that included drinking speed were the most sensitive to detect sick calves in a study with 10 auto feeder farms;[21] however, the application of statistical process control charts was not useful as a stand-alone test to predict or detect disease in these preweaned calves housed in groups (17 ± 5 calves per group).

These studies are some examples that feeding behavior collected by automated feeder software can be helpful in detecting sick calves. However, calf observation by the caretaker is critical and needs to be combined with the daily health warnings provided by the software.

Conclusions

The milking process fits well with robotic technology. This technology continues to improve and more options will most likely be available in the future. It is expected that labor availability in many parts of the world will continue to drive the adoption of RMS. Taking a whole system approach in design and management will maximize RMS performance and efficiency. Feeding cows in RMS requires adjustments on ration formulation to address the need to entice cows to the RMS box. In addition, various factors may affect attendance to the RMS box and influence milk production. The RMS will continue to improve and provide additional precision individual-cow measurements that help improve herd performance and animal health.

Automated milk feeders for raising calves in groups are growing in popularity. This trend will probably continue as producers want more labor flexibility and consumers want animals to have a more natural life. Feeding calves in groups allows calves to express some natural behaviors that cannot

be expressed when housed individually, but offers some challenges in relation to maintaining good health. Good health and low mortality rate are achievable when using automated feeders to raise preweaned calves as long as appropriate management and maintenance of the feeding equipment and cleanliness of the calf environment are emphasized and implemented, along with daily visual observation of the calves by the caretaker.

Acknowledgements

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