The Impact of Robotic Milking on Milk Quality, Cow Comfort and Labor Issues

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Robotic milking has gained widespread acceptance, particularly in western Europe, as a way to reduce labor requirements on dairy farms and as a way to improve the lifestyle of dairy farm families operating dairies with 40 to 400 milking cows. At the end of 2009, worldwide, an estimated 8000 commercial dairies used one or more robotic milking stalls to milk their cows (De Koning, 2010) and it is likely that this number has now surpassed 10,000. The first commercial robotic milking systems in North America were installed in Ontario, Canada in 1999, and there are an estimated 500 farms, predominantly in Canada and the north eastern USA milking with robots today. The wide spread adoption of this technology suggests at least a measure of success in helping dairy farmers achieve greater labor efficiency and a better lifestyle. But field experience on commercial farms, also suggest that there is wide variation in the amount of labor saved and in the overall satisfaction of early North American adopters of this technology.

The success of robotic milking is dependent on the cow and her willingness to visit the robotic milking stall voluntarily with sufficient frequency to support an economic level of milk production. Since the milking herd never leaves the barn, the applications of other management activities such as stall maintenance, manure removal, and cattle handling require a different approach than with conventional milking. Capitalizing on the opportunities for labor saving hinges on the ability of robotic milking farms to achieve frequent voluntary milking and on minimizing the work of cattle handling. The health and comfort of the cow is a major factor in visiting behaviour, making it critical to the success of robotic milking. Numerous studies of milk quality in robotic milking herds suggest that some aspects of milk quality may be slightly poorer on robotic dairies than in conventional milking systems where an operator is present during milking.

This paper offers a practical overview of success factors contributing to labour efficiency, cow comfort and milk quality in robotic milking herds. As a relatively new way of milking cows, this technology continues to improve, and has undergone substantial evolution in the last ten years. Both the technology available today and the management and facilities that producers place around it are more reliable, more cow friendly and more efficient than many of the systems on which data was collected and reported over the last 20 years, As a result much of the historical data in the literature is of little value in defining the robotic milking experiences of farms who adopt this technology now and in the future. Despite the large body of published literature, observations presented here will be partially based on unscientific, current field observations with newer installations.

Labour efficiency

In a field survey of 107 farms Mathijs (2004) found an 18% saving in labour. Herds in Sweden, with 1 robotic milking stall saved 2 minutes per cow per day in total labour compared to parlor herds (Gustafsson, 2004). A Canadian study of similar vintage (McKnight, Rodenburg and Fisher, 2003) paired 22 robotic milking herds with parlor herds of similar size and found that milking and related set up and clean up took 2.26 minutes per cow per day less time in robotic milking herds (1.02 vs. 3.28 minutes). Using data collected in 2003, a Dutch study published in 2007 (Bijl, Kooistra and Hoogeveen, 2007) reported that on average 1.45 units of labour defined as 50 hours per week, filled 828, 761 Kg of milk quota (1,827,075 lbs.) from 105 cows on 31 robotic farms. These farms were paired with 31 others who had made investments in new parlors at the same time. The parlor farms filled 853,620 Kg of quota with 110 cows and 1.87 units of labour. Milk production was similar between these herds, and the robotic farms required 29% less labour. In Finland, labour per cow was 30% less on robotic milking farms than on conventional dairies in data collected in 2005 through 2007 (Heikkila, 2010).

Two labour related aspects of robotic milking that create new challenges include the need to fetch cows that don't attend voluntarily, and the added complexity involved in sorting and restraining cows for handling. If these two tasks require an excessive amount of time, the labour efficiencies gained from not having to milk cows may be largely lost in the new work of fetching and handling. For example, in an informal survey of robotic milking herds conducted in Ontario and Quebec in 2005, 35 free traffic herds fetched an average of 16.2% of the milking cows at least once per day and 9 herds with forced traffic fetched 8.5% of cows. Some individual herds fetched as many as 40% of the cows and experienced much poorer labour efficiency as a result. Simple fetch routes that do not involve dead ends or multiple escape routes for cows being moved to the fetch pen, will reduce labor requirements, but decreasing the number of cows requiring fetching is the more important component of managing fetching in a labor efficient manner. Today, many herd owners with new robot models in well designed and well managed free traffic barns report fetching 0 - 2% of the herd.

The number, production level and milking speed of the cows determine how much of the time the milking stall is occupied. As "free time declines the number of cows that require fetching increases (Rodenburg 2002). A review of feeding related factors (Rodenburg, 2011) reported that high levels of concentrate feeding and the feeding of weak dusty pellets or mash in the robot, increased the need to fetch cows. Pellet ingredients that increased fetching included corn, fat and dried grass, while barley/oat based pellets decreased the need for fetching. (Madsen, 2010).

When cows access the robot and feeding areas without restriction using a free traffic layout there are usually more cows that require fetching than when they are forced into a specific routing by one way gates in a forced traffic layout. Hence the choice of free or forced traffic will have an impact on labour efficiency. Since this choice also has a major impact on cow comfort it will be discussed later in the paper.

Since cows never leave the barn, and are milked continuously at unpredictable times, there is no single time of the day that cows can be conveniently sorted from the herd over a short period of time as compared to parlor milking where this can be done as cows return from the milking parlor. Effective separation from a robotic milking stall requires the provision of a sort gate at the robot exit or in a return lane, that accesses a separation area that provides manger space, water, a resting area and a route back to the robot for milking. If handling functions such as pregnancy examinations are to be done using milking time separation, the sorting out process needs to be started at least 12 hours before the planned herd health visit. A convenient way to provide for this is described in the section on barn layout. Handling cows in headlocks over the entire length of the manger in the milking cow housing area is another way of restraining cows for herd health and other group handling. While this will work in a very similar fashion to parlor milked herds, cows milked with a robotic milking system are less inclined to eat at the same time, and will not be as easy to coax into the headlocks.

When only the impact of robotic milking is estimated and compared, it would appear that the typical labour saving is 20 to 30% compared to conventional parlor milking. But in the field, the total impact of adopting robotic milking along with other precision technologies and automation is substantially greater. According to the 2010 Ontario Dairy Farm Accounting Project (Dairy Farmers of Ontario, 2011) the average amount of labour required to produce a hundred weight of milk on typical Ontario dairies is 0.65 hours. (1.47 hours per hectolitre). An estimated 15% of this is the field work of growing crops for the herd, leaving 0.55 hours per cwt. (1.25 hours per hectolitre) of in-barn labour related to the milking herd and replacements. With an average herd size of 75.5 cows, labour per cow is reported as 109.45 hours per year. Assuming 15% of the cows are dry, and adjusting for the 15% cropping related work, labour per milking cow per day would be approximately 0.30 hours. This data comes from 65 farms selected to represent a cross section of Ontario herds including tie stall and freestall herds of various sizes. By way of contrast the owner of one robotic milking herd with 120 cows producing 3 million lbs. of milk (1.36 million Kg) reported spending an average of 32 hours per week on livestock related work excluding cropping. This farm takes advantage of other labour saving technologies such as pedometers, robotic calf feeding and slatted floors with a robotic slat cleaner, along with 2 robotic milking stalls in a well laid out barn. The total estimated labour per hundred weight of milk on this farm is .055 hours per cwt (.125 hours per hectolitre) or one tenth of the labour of an average Ontario dairy farm. On a per cow basis, this farm is applying .038 hours per cow per day of labour to complete all tasks related directly to the dairy herd. In a survey of free stall dairies in Ontario, (Rodenburg 2010) the average daily labour reported by 69 farms with an average of 169 milking cows was 0.18 hours per milking cow per day. This is substantially lower than the provincial average of 0.30 hours but still 5 times the labour reported by the highly automated robotic dairy which reported .038 hrs per cow per day.

<u>Cow comfort</u>

The impact of robotic milking on most aspects of dairy herd management were studied in the "EU project". Fertility, metabolic health, body condition, and lameness, as well as udder health (Hillerton 2004) were monitored in herds in Britain, Denmark and Holland over a period before and after installation of the robotic milking system. Body condition did not change in Denmark and UK herds and declined slightly in Dutch herds. No clear changes in locomotion scores occurred in the study. In the UK average locomotion scores were poorer a year after the start of robotic milking, but in several herds, grazing was eliminated from management at the time robots were introduced and this was thought to be a contributing factor. These authors concluded that robotic milking did not alter health parameters in any significant way.

Studies comparing stress levels in cows milked in robotic systems vs. in parlors, have found that stress levels during milking were similar (Hopster 2002, Hagen 2005) or lower (Hagen 2004) but each of these studies speculated that higher milk cortisol concentrations reflected higher stress in the robotic milking cows between milkings. All of these studies involved forced cow traffic with pre-selection and in one case (Hagen 2005) the authors speculated this may have contributed to the observed slightly higher stress levels between milking. A more recent study (Gygax 2006) did not find differences in cortisol levels between cows milked in forced or free traffic robotic milking systems or auto tandem parlors.

Dairy farmers milking with robotic systems report that in terms of their interaction with people, cows in robotic milking herds are very quiet, and generally ignore workers who are bedding stalls or fetching other cows in among them. In "human approach" tests, fetched cows more frequently avoided the test person than non fetched cows.(Rousing 2005) Since cows in parlor herds are all "fetched" two or three times daily, perhaps the observation that robot herds are much more restful can be linked to the fact that most cows in robotic herds are rarely disturbed by humans.

Although there are no published studies examining differences in cow comfort while in the milking stall, field experiences suggest that cows prefer more open space in the stall. With Lely robots, the A2 model had limited space in the box and used a butt plate in contact with the cow to locate her position in the stall. Herds that replaced these systems with either A3 or A4 models that include more space for the cow and which use position locators that do not contact the animal, experienced a clear and immediate increase in visits. In robotic milking systems that restrict the length of the stall with adjustment of the feed bowl, correct adjustment that does not crowd the cow to the point of discomfort, is helpful in encouraging frequent milking visits.

General cow comfort in the barn plays a major role in successful robotic milking. For example several studies point to the fact that lameness decreases the frequency of voluntary attendance for milking and increases the need to fetch cows. (Grove 2004, Bach 2006, Borderas 2008). It follows that facilities and management for robotic milking herds should focus on minimizing lameness issues. Barn design features and management practices that contribute to good foot health include:

- comfortable free stalls with adequate lunging space and a soft bed with good grip, to encourage long lying times and well rested cows, as well as dry hooves that are less prone to infection.
- frequent cleaning and bedding of freestalls
- frequent automatic cleaning of alley floors to keep them clean and dry.
- good ventilation to keep floors and feet dry.
- free traffic to minimize the time cows spend standing and waiting
- a bedding pack with robot access for fresh and lame cows that provides additional comfort for cows recovering from calving or from a clinical lameness condition.
- regular strategic footbathing

- regular attention to routine hoof care and trimming and treatment of problem cows in a convenient handling chute.

Other factors that contribute to cow comfort in robot barns include:
- large open areas in front of the robotic milking stalls with multiple escape routes, so that timid cows can confidently approach the robotic milking area
-floors that offer secure footing,
- spacious alleys that allow for easy movement of cows though the barn.

Forced vs. Free Cow Traffic

Since the choice of forced vs. free traffic has a substantial impact on both labour efficiency and cow comfort it is appropriate to discuss it in this paper. Numerous studies have shown that attendance, while no longer "voluntary" in the pure sense, can be improved by forcing the cow to enter the robotic milking stall or an associated selection gate en route from the resting area to the feed manger or on her return from the manger to the resting area. This is commonly referred to as "forced" cow traffic. There are at least four common variations of "cow traffic" strategies used in robotic milking herds today. (1) Free cow traffic, where cows can access feeding and resting areas of the barn with no restriction. (2) Forced cow traffic with one way gates blocking the route from the resting area from the feeding area so cows leaving the resting area must enter the milking box, to be milked if the interval since the last milking makes her eligible, or "refused" if the milking interval is too short. After passing through the milking stall, the cow is released to the feeding area and can only return to the resting area through a one-way gate. (3) Forced cow traffic with "pre-selection" adds an entry lane where a sort gate directs cows eligible for milking to the holding area and ineligible cows to the feeding area. This reduces waiting times for milking and for feed because only cows eligible for milking pass through the milking stall. Pre-selection can also be provided by selection gates in crossovers away from the robot, which open only for cows ineligible for milking. (4) Feed first forced traffic is a reversal of (2) which allows cows access to the manger from the resting area via one way gates, but they can only return to the resting area through the robotic milking stall, or through pre-selection gates that direct cows ineligible for milking directly to the free stalls or bedding pack.
Numerous studies report slightly higher milking frequency and a much-reduced need to fetch cows with forced traffic. (Hoogeveen, 1998; Van't Land, 2000). (Harms, 2002) reported 2.29, 2.63 and 2.56 milkings and 15.2, 3.8 and 4.3 fetching acts per day with 49 cows in free, forced and forced with pre-select traffic respectively. The number of meals was higher at 8.9 with free cow traffic, than with either forced or forced with pre-select, where cows consumed 6.6 and 7.4 meals respectively. Forage intake decreased when cows were switched to forced traffic and went back up in the forced with pre-select phase. (Thune, 2002) reported 1.98, 2.56 and 2.39 milkings, and 12.07, 3.86, and 6.46 feeding periods with free, forced and forced with pre-selection traffic respectively. In this study, dominant and timid cows spent an average of 78 and 95 minutes waiting for milking in a free traffic setting vs. 124 and 168 minutes with pre-selection and 140 and 240 minutes with forced traffic. Timid cows waited an average of 4 hours per day for milking because, they are directed into the fetch pen en route to or from the manger, but higher ranking cows continually beat them into the robot, leaving them trapped in the fetch pen for several hours. From a cow comfort perspective this is highly undesirable and may lead poor metabolic health and increased lameness, eventually leading to a further deterioration in visiting

behaviour. On Ontario farms with forced cow traffic (Rodenburg and Wheeler, 2002), average number of daily visits per cow, and therefore visits to the manger to consume TMR was 3.40 $\pm$ 0.44. This is many meals fewer than the 12.1 (Vasilatos, 1980) per day reported in a trial with free access and parlor milking. Fewer meals are associated with lower dry matter intake (Dado and Allan, 1994) and forced cow traffic has been shown to have this effect (Prescott et.al., 1998). Pre-selection systems result in some improvement in feed access but number of meals remains lower than with free traffic. Cows in forced traffic situation also spend more time waiting for milking and less time lying down, (Winter and Hillerton, 1995). It is also of some concern that when a cow is in pain from a clinical case of mastitis or when she is lame, she will avoid milking in a free traffic situation and this alert the herdsman to her plight. Faced with the choice of starvation or milking this cow is more likely to go unnoticed in a forced traffic setting.
In the most recent comprehensive comparison for the two traffic systems (Bach et. al., 2009), cows were fed a partial mixed ration and up to 6.6 lbs of concentrate in the milking stall. Results summarized in table 1, illustrate that milking behavior, eating behavior and milk composition were all influenced by the choice of traffic system, but total dry matter intake and milk production were similar.

Table 1: (Bach et. al. 2009) Feeding and milking behavior, and milk production and composition of cows with free vs. forced traffic.

(Per cow per day)	Free Traffic	Forced Traffic	SE	P-value
Total Milkings	2.2	2.5	0.04	<0.001
Fetched Milkings	0.5	0.1	0.03	<0.001
PMR* intake	41.0 lbs. (18.6 Kg)	38.8 lbs. (17.6 Kg)	1.34	0.24
No. of meals of PMR	10.1	6.6	0.30	<0.001
Concentrate Intake	5.5 lbs. (2.5 Kg)	5.5 lbs. (2.5 Kg)	0.09	0.99
Milk production	65.7 lbs (29.8 Kg)	68.1 lbs. (30.9 Kg)	1.74	0.32
Milk fat %	3.65	3.44	0.078	0.06
Milk protein %	3.38	3.31	0.022	0.05

* a partial mixed ration formulated for 15.4 lbs (7 Kg) less milk than the average production of the group.

From a feeding standpoint forced traffic reduces the need to provide highly palatable feed in the robotic milking stall. As long as there is no alternative, most cows will go through the robotic milking stall out of sheer need to consume the ration at the feed manger, but reduced number of meals, reduced feed intake, reduced resting time, and longer waiting times, especially for timid cows make this system less desirable from the stand point of cow welfare and long term productivity.

As illustrated in table 3 later in this paper, with current technology there are numerous examples of robotic milking herds with free traffic that report over three milkings per day and very few fetch cows. There are also numerous examples of forced traffic herds that report high feed intake, good production and few health issues. This demonstrates that both systems can work successfully under ideal circumstances. But when less than ideal conditions prevail, with free traffic the dairyman suffers the consequences in the form of fewer milkings and more fetch cows. With forced traffic the cows suffer the consequences with lower feed intake, and longer waiting times. Since problems are much more likely to be resolved quickly when the dairyman suffers, free cow traffic is the preferable management system.

Milk Quality

Because milking is unattended and continuous, robotic milking presents new challenges to maintaining udder health and producing quality milk. In general robotic milking herds experience slightly higher somatic cell counts and total bacteria counts than herds milked with conventional systems. In a recent review, De Koning (2010) reported the results in Table 2 as typical for Dutch dairy herds with parlors and robots.

Table 2. Milk Quality results for farms before and after introduction of an automatic milking system. (De Koning 2010)

	Conventional Milking		Robotic Milking	
	2X milking	3X milking	Before	After
Bacteria Count (1000/ml)	8	8	8	12
Cell Count (1000/ml)	181	175	175	190
Freezing Point (^{o}C)	-0.520	-0.521	-0.521	-0.516
Free fatty acids (meq/100 g fat)	0.44	0.54	0.41	0.59

These differences are small and well within the limits of acceptable milk quality, but they do point out that additional care is needed to maintain good milk quality in robotic milking herds. Higher bacteria counts likely result from a combination of inadequate cleaning of exceptional dirty udders and cooling challenges related to cooling a small volume of milk, during the first few hours after milk pick up.

Differences in somatic cell count are also small and related to challenges in detecting new cases of mastitis. Continuing development of more sophisticated sensors and computerized diagnostics should improve the performance of robotic systems in the future. The impact of robotic milking on udder health has been thoroughly reviewed (Hovinen 2011) very recently.

Elevated freezing points for robotic milking likely reflect residual water left in milking equipment from frequent rinsing of liners.

Free fatty acids are formed as a result of lipolysis and can result from physical damage of milk fat globules during milk handling, but they may also result from animal related factors such as the health, diet, and milking frequency. As illustrated by the difference between 2x and 3x conventional herds, part of the difference for robotic herds can be explained by more frequent milking. Higher air intakes for robotic systems are likely a further contributing factor (De Koning 2010)

Helgren & Reinemann (2006) studied milk quality of 12 AM farms in the USA for three years as part of a pilot study of AM technology in the USA. Daily records of bulk tank somatic cell count (SCC) and total bacterial count (TBC) data were analyzed and compared to corresponding data from a cohort conventional farms in Wisconsin as well as data from European AM installations. The geometric means for all farms were 268,000 cells/ml SCC and 13,300 cru/ml TBC. There was no significant difference in SCC between AM farms and the cohort of conventional farms, and bacteria counts were lower than from conventional farms. Both SCC and TBC decreased as the amount of time that farms utilized robotic milking increased.

One aspect of milk quality that is seldom discussed in the literature is the incidence of inhibitor penalties. When a cow is treated with antibiotics on a robotic dairy, it is customary to program the milking system to discard the milk from the treated cow for the prescribed period, prior to treating the cow. Since the robotic system is much more reliable in identifying cows and discarding milk than human milkers, this is one area where milk quality from robotic milking herds far exceeds the performance of conventional milking. In 12 years of robotic milking in Ontario, no robotic dairy has ever incurred an inhibitor penalty.

Barn Design for Robotic Milking

Several authors (Hovinen 2011, Rodenburg 2011, De Koning 2010, Hillerton 2004, Thune 2002) have alluded to the importance of the design of housing systems for robotic milking and their impact on labour efficiency, cow comfort, milk quality and many other aspects of successful application of this technology. The barn layout illustrated in Figure 1. illustrates a number of features that lead to positive outcomes for labour efficiency and cow comfort. It is presented as an example of the kind of features that can be included to minimize handling labour and maximize cow comfort. The split entry holding area simulates voluntary entry for fetched cows, minimizes interference for other cows and is the least labour for the owner. A large open area in front of the robots with multiple escape routes gives timid cows the confidence to attend voluntarily. Cow brushes, pasture selection gates and computer feeders should be placed far away from this area to spread out the areas of activity and minimize stressful interactions. Simple cow routing and gating makes all handling and fetching a one person job. Perimeter feeding keeps cows out of the rain and sun, and reduces the risk of frozen manure in alleys. But the main benefit is that cows never have to cross a feed alley, making grouping, and access to the handling area much more convenient. The pack area for fresh and lame cows ensures maximum comfort and provides voluntary access to the milking robot. This pack is combined with the calving pens so all bedded areas are in one convenient place. The barn in Figure 1 also provides a practical separation area by making flexible use of space that is available to dry cows on days when only a few cows are separated. Using a 3 way sort on one robot and a two way sort on the other, allows cows to be separated from both stalls into one handling area and still allows voluntary access for cows in the bedding pack. Each robot is used strategically to offer access to special groups of fresh and lame cows, separated cows, and/or close up heifers. With two robots there is access from the bedding pack and the separation area. When there are no separated cows, close up heifers and cows can have access for training. With direct access for all groups to a centralized handling area, this layout permits simple handling of cows separated from either robot, as well as one man handling of cows fetched from any group. Note that equipment storage, water and hydro, are convenient to the handling area. In this illustration all milking robots face the same way, so no retraining is needed when cows go from group to group. In a field survey of 11 herds with two robots in one group, 39% of cows used both robots 40 to 60 % of the time, defined as "cross use" and 20% of cows used either one or the other robot more than 90% of the time defined as "selective use". In a comparison of layouts it was found that selective use was lowest when all robots faced the same way (Gerlauf 2009). Since cows never leave the barn, all tractor work is very disruptive and should be avoided, but in a sand bedding option, wide alleys, straight lines through the barn, multiple crossovers and free traffic are recommended. There are several ways that this layout can be expanded from 2 to 3, 4, 6, or 8 robots by mirroring the barn and adding robots on the center cow platform, while retaining the convenience of central handling

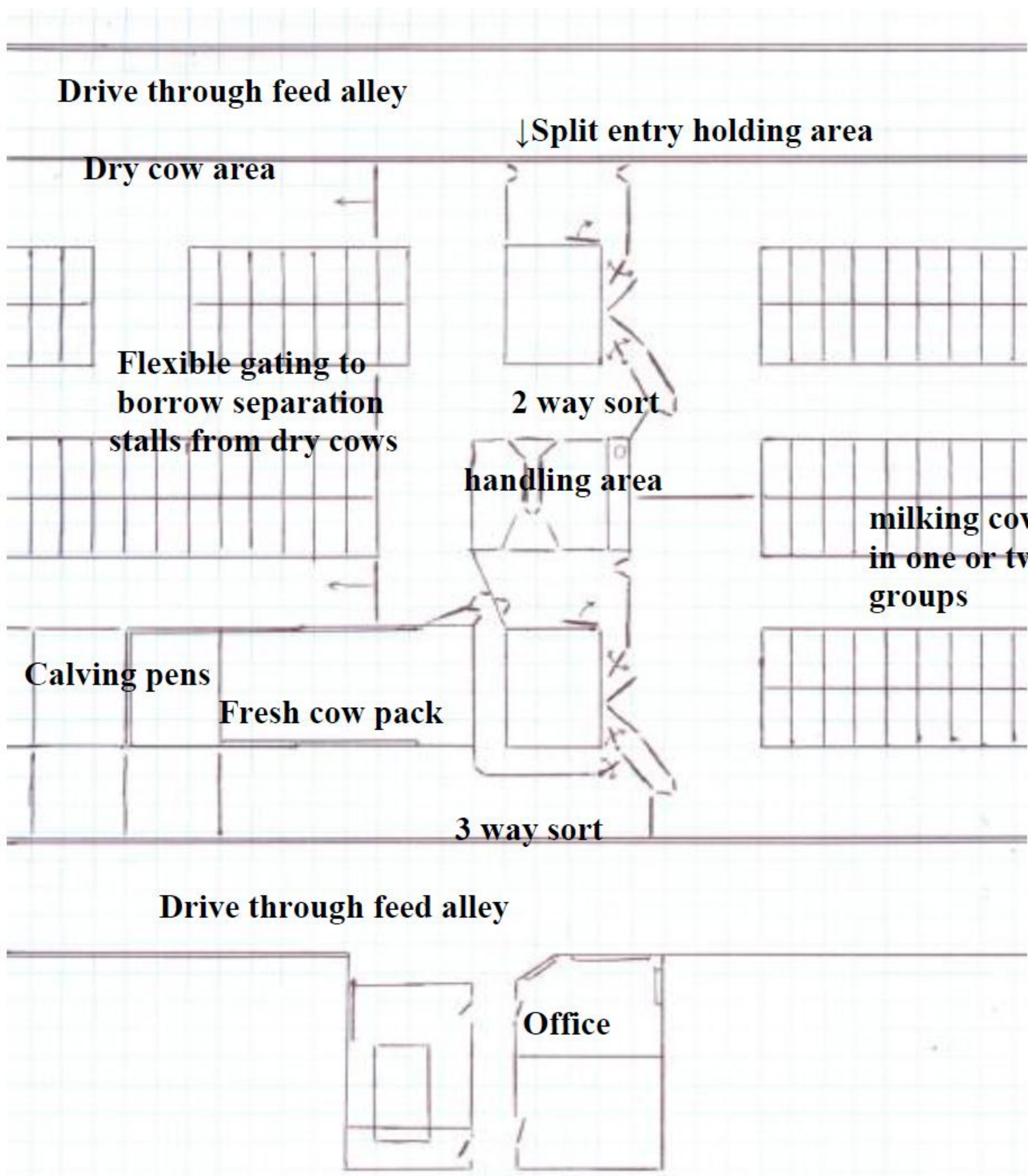

Figure 1. The robot and handling area of a 2 robot barn.

and simple cow movement.

Challenges in Emerging Markets

The brief, 12 year history of robotic milking in North America includes many successes and several failures as well. In many cases poor outcomes have resulted from poor facilities design, inexperienced installers and inadequate management support and training. Since the technology also continues to change rapidly, results reported in research that is more than 3 or 4 years old do not reflect the current capabilities and performance of new commercial installations. The data in Table 3 is a summary of 10 farms representing all of the installations running for 6 months or more from an experienced dealer in one region of Canada. All ten herds are free traffic layouts, including 4 new barns and 6 renovations of existing barns. These systems are all new within the last 4 years and reflect the technology currently on the market. While new technology continues to emerge, as illustrated here, single box robotic milking systems from established manufacturers installed by experienced technicians in properly renovated or designed barns, and managed by properly trained dairy farm staff are capable of delivering excellent results.

Table 3. performance of all robotic milking systems installed by an experienced dealer in one region of Canada. Nov. 2011 Quality and performance data

Farm #	No. of Cows	No. of Robots	SCC (000)	Bacteria (000)	Milking/ day	Refusals/ day	Milk production (Kg/cow/day)	Months since start up
1	59	1	136	8	3.2	1.5	36.2	43
2	103	2	229	8	3.1	1.7	35.8	41
3	128	3	230	12	3.3	1.5	37.0	37
4	120	2	82	12	3.1	1.0	32.2	36
5	59	1	248	7	3.2	2.2	33.5	34
6	210	4	183	2	3.2	1.2	40.1	24
7	110	2	148	10	3.2	2.0	36.4	19
8	120	2	236	7	2.8	2.6	28.1	18
9	60	1	148	8	3.3	1.8	38.3	12
10	280	5	173	15	3.0	1.0	33.6	6
Ave.	125	2.3	182	10	3.14	1.65	35.1	27

References

Bach, A., C. Iglesias, S. Calsamiglia, and M. Devant, (2007) Effect of Amount of Concentrate offered in Automatic Milking Systems on Milking Frequency, Feeding Behavior, and Milk Production of Dairy cattle Consuming High amounts of Corn Silage, Journal of dairy Science 90-11, pg 5049-5055

Bach, A., M. Dinarés, M. Devant, and X. Carré, 2007, Associations between Lameness and Production, Feeding and Milking Attendance of Holstein Cows Milked with an Automatic Milking System. J. Dairy Res. 74 pp 40 -46

Bijl, R., S.R. Kooistra, and H. Hogeveen, 2007, The Profitability of Automatic Milking on Dutch Dairy Farms, 2007, J. Dairy Sc. 90 pp 239-248

Borderas, T.F., A. R. Fournier, J. Rushen, and A.M. de Passillé. 2008. Effect of lameness on dairy cows' visits to automatic milking systems.
Can. J. Ani. Sci. 88: pp 1-8.

Dairy Farmers of Ontario, 2011, Ontario Dairy farm Accounting Project Annual Report 2010, http://www.milk.org/Corporate/pdf/Publications-ODFAPReport.pdf

De Koning, C.J.A.M., 2010, Automatic Milking - Common Practice on Dairy Farms, Proc. of the First North American Conference on Precision Dairy Management, pp 52 - 67

Grove, S., T.B. Bennedsgaard, M.Dam Rasmussen, and C. Enevoldsen, 2004, A Study of the Effect of Lameness on Voluntary Milking Frequency of Dairy Cows Milked Automatically, in Automatic Milking: A Better Understanding, Wagening Academic Publishers, Wageningen, the Netherlands, p 171

Gerlauf, J.S, G.J. VanderVeen, and J. Rodenburg 2009, “preference Behaviour of Cows Choosing a Robotic Milking Stall, in Abstracts of the 2009 European Association of Animal Production,Wageningen Press.
Gustafsson, M., 2004, Working Time Studies in farms with Conventional and Automatic Milking, in Automatic Milking: A Better Understanding, Wagening Academic Publishers, Wageningen, the Netherlands, p 488

Gygax, L. I. Neuffer, C. Kaufmann, R. Hauser, and B. Wechsler, 2006 Milk Cortisol Concentration in Automatic Milking Systems Compared with Auto-Tandem Milking Parlors. J. Dairy Sc. 89 pp 3447 - 3454

Hagen, K., D. Lexer, R. Palme, J. Troxler, S. Waiblinger, 2004, Milking of Brown Swiss and Austrian Simmental Cows in a Herringbone Parlor or an Automatic Milking Unit, Applied Animal Behaviour Science 88 pp 209-225

Hagen, K., J. Langbein, C. Schmied, D. Lexer, and S Waiblinger. 2005, Heart Rate Variability in Dairy Cows - Influences of Breed and Milking System, Physiology and Behaviour 85 pp 195-204

Harms, J., G. Wendl, and H Schon, 2002. "Influence of Cow Traffic on Milking and Animal Behavior in a Robotic Milking System" in Proceedings of the First North American Conference on Robotic Milking, March 20-22, 2002, Toronto Canada, Wageningen Press, Pp II 9 - 14

Helgren, J.M. and D.J. Reinemann, 2006. Survey of Milk Quality on U.S. Dairy Farms Utilizing Automatic Milking Systems. Transactions of the ASABE, 49(2) pp 551-556

Heikkila, A., L. Vanninen and E. Manninen, 2010, Economics of Small Scale farms having Robotic Milking, Proc. of the First North American Conference on Precision Dairy Management, pp 68 - 69

Hillerton, J.E. J. Dearing, J. Dale, J. J. Poelerands, F. Neijenhuis, O.C. Sampinon, J. D. H. M. Miltenburg and C. Fossing, 2004 Impact of Automatic Milking on Animal Health. in Automatic Milking: A Better Understanding, Wagening Academic Publishers, Wageningen, the Netherlands, p 125 - 134

Hogeveen, H., A.J.H. van Lent, and C.J. Jagtenberg 1998. "Free and One-Way Cow Traffic in Combination with Automated Milking" Proceedings of the 4th International Dairy Housing Conference St. Louis Missouri January 28-30 1998 ASAE pp. 80-87

Hopster, H., R.M. Bruckmaier, J.T.N. Van der Werf, S.M. Korte, J. Macuhova, G. Korte-Bouws and C.G. van Reenen, 2002, J. Dairy Sc. 85 pp 3206-3216

Hovinen, M., and S. Pyorala, 2011, Invited Review: Udder Health of Dairy Cows in Automatic Milking, J. Dairy Sc. 94 pp 547 -562

Madsen, J., M.R. Weisbjerg, and T. Hvelplund, 2010, Concentrate composition for Automatic Milking Systems- Effect on Milking Frequency. Livestock Science 127, 45-50

Mathijs, E, 2004, Socio-economics Aspects of Automatic Milking, in Automatic Milking: A Better Understanding, Wagening Academic Publishers, Wageningen, the Netherlands, pp 46-55

Fisher, J., D.R. McKnight, and J. Rodenburg, 2003, Economics of Robotic Milking Systems for Dairy Cows in Ontario 2002, University of Guelph Research Report, http://www.kemptvillec.uoguelph.ca/_pdf/final_report_two.pdf

Rodenburg, J. and B. Wheeler, Strategies for Incorporating Robotic Milking into North American Herd Management, 2002, in Proc. of the First North American Conference on Robotic Milking, pp III 18 -32

Rodenburg J., 2010, Labour Costs on Ontario Dairy farms and their Implications for Precision Technologies, Proc. of the First North American Conference on Precision Dairy Management, pp 20 - 21

Rodenburg, J., 2011, Designing Feeding Systems for Robotic Milking, in Proc. of the Tri-State Nutrition Conference, April 19 - 20, 2011, pp 127 - 138

Rousing, T., J.H. Badsberg, I.C. Klaas, J. Hindheded, and J.T. Sorensen, 2006 The Association Between Fetching for Milking and Dairy Cows' Behaviour at Milking and Avoidance of Human Approach - An On-Farm Study in Herds with Automatic Milking Systems, Livestock Science 101 pp 219-227

Thune, R.O., A.M. Berggren, L. Gravas, and H. Wiktorsson, 2002, Barn Layout and Cow Traffic to Optimize the Capacity of n Automatic Milking System." in Proceedings of the First North American Conference on Robotic Milking, March 20-22, 2002, Toronto Canada, Wageningen Press, Pp II 45 - 50

Vasilatos, R. and P. J. Wangsness. (1980) Feeding behavior of lactating dairy cows as measured by time-lapse photography. J. Dairy Sci. 63:412.

Van'tLand, A., A.C. Van Lenteren, E. Van Scooten, C. Bouwmans, D.J. Gravesteyn and P. Hink, 2000, Effects of Husbandry System on the Efficiency and Optimization of Robotic Milking Performance and Management. In Robotic Milking: Proc. of the International Symposium held in Lelystad, the Netherlands 17-19 August 2000, Wageningen Press. pp 167-176

Winter, A., and J.E. Hillerton, 1995, Behavior associated with feeding and milking of early lactation cows housed in an experimental automatic milking system. Applied Animal Behavior Science 46, 1-15