FEEDING THE ROBOTIC MILKING HERD

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INTRODUCTION

Robotic milking has gained widespread acceptance, particularly in western Europe, as a way to reduce labor on dairy farms, increase production per cow, and improve the lifestyle of dairy farm families milking 40 to 250 cows (De Koning 2010). The growing popularity of this technology is evident in its rapid rate of adoption. In 2009, the estimated number of robotic dairy farms worldwide was 8000 (De Koning 2010). Just 6 years later, in 2015, Barkema et. al. (2015) suggest this number has more than tripled to 25,000 dairy farms worldwide. The percentage of herds using this technology is highest in Scandinavian countries and the Netherlands (Barkema et. al. 2015). Widespread adoption in these countries suggests at least a measure of success in helping dairy farmers achieve greater labor efficiency and a better lifestyle, but field experience suggests there is wide variation in the amount of labor saved and in the overall satisfaction of early adopters.

Two excellent reviews summarizing the impact of robotic milking on udder health (Hovinen and Pyoralia, 2011) and on cow management, behavior, health and welfare (Jacobs and Siegford, 2012) have been published. When dairy producers with robotic milking experience, are asked to list success factors they usually rank feeding management and feed quality as number one, however formal research defining effective feeding strategies, is quite limited. Feeding research related to robotic milking has been reviewed (Rodenburg, 2011) and a more current review is forthcoming (Bach and Cabrera in press). The information below includes a mix of research results and current on farm practice. Where my recommendations and guidelines are not clearly supported by research they should be recognized as anecdotal and it is my hope that they might lead to further formal study to confirm or refute them.

GOALS IN FEEDING THE ROBOTIC MILKING HERD

The goals of traditional dairy feeding programs include meeting the nutritional requirements of the cow in a way that ensures that she stays healthy, using feed ingredients that are economical and using labor efficient and cost effective feed delivery systems. With robotic milking there is a very important fifth goal and that is to use feed to entice the cow to visit the robotic milking stall regularly and frequently. Motivated cows visit voluntarily thereby decreasing the need for fetching, and they will visit more frequently at more uniform intervals leading to higher milk production.

Interactions among the activity or behavior of the dairy cow, her diet and feed consumption, her health and her milk production are complex and become even more complex with voluntary milking. Part of the complexity among these relationships is that none can claim to be distinctly "cause" and none is distinctly "effect". For example, standard feeding management advice encourages producers to provide fresh feed more often, to stimulate a change in behavior, in the form of more frequent meals. This change in behavior is predicted to "cause" a change in diet, in the form of higher feed intake, which subsequently "causes" higher milk production. Alternatively, diet may cause a change in health and behavior, when a low fiber, high grain ration, is blamed for a high incidence of lameness, "causing" a change in behavior in the form of fewer trips to the feed bunk, subsequently "causing" lower feed intake and lower production. But when 3x milking, elicits an 8 to 12 lb. production response, higher production "causes" greater feed intake. In these examples, each of the four attributes, behavior, diet, health and production is "cause" in some cases, and effect in others.

When cows are milked at fixed intervals, external control of the "milking frequency" variable may limit variation in the other attributes. For example, under conditions of heat stress, cows reduce their activity and reduce their feed intake. Production suffers, but twice daily milking, provides a baseline stimulus for production. Robotic milking is voluntary and variable, adding a new dimension to these interactions. If hot weather, reduces activity, it results in both lower feed intake and reduced milking frequency. Without a fixed, milking interval, heat stress in the robotic herd could start a downward spiral of reduced interest in feed, leading to less frequent milking, leading to lower production, and in turn even less interest in feed, etc. Based on this example, feeding management and an understanding of the interactions between diet, behavior, health and production take on a greater importance when robotic milking is considered.

One specific aspect of nutrition and health is worthy of special note in relation to robotic milking. Several studies have found that lame cows exhibit lower voluntary milking frequency and are much more likely to require fetching. (Bach et. al. 2007, Borderas et.al 2008). Lameness is a multi-factorial problem influenced by nutrition, and while a discussion of nutritional factors contributing to it is beyond the scope of this paper, these factors should be given special importance when formulating diets for robotic milking herds.

CURRENT PRACTICE AND COMMERCIAL RECOMMENDATIONS

Three approaches are currently used successfully in feeding robotic milking herds in confinement housing. The most common approach with free traffic is a "partial mixed ration" (PMR) formulated for a production level 18 lbs. below the mean of the group, combined with 4 to 18 lbs. of pelleted concentrate fed according to production in the milking box. In robotic milking systems, cows are assigned to different feeding tables based on age or stage of lactation and each table allocates the feed fed in the robot according to the parameters set within it. The tables typically include a “fresh cow” table where each cow is fed 4 to 7 lbs. the day of calving and this is increased 0.4 to 0.7 lbs. per day daily from calving to 7 to 14 days fresh, regardless of production level. If the production average of the herd is 80 lbs. of milk, this cow is eating about 15 lbs. of concentrate from the PMR so her total concentrate intake will increase gradually from 20 lbs. to 28 lbs. by 2 weeks fresh. Increasing grain feeding gradually is helpful in the prevention of displaced abomasum (Shaver 1997) and rumen acidosis. This is followed by an “early lactation table” on which cows are fed “according to production” but at a level that is slightly higher than their nutrient requirements, to challenge them to produce more and to compensate for any weight loss earlier in this period. At a fixed number of days in lactation, after cows have peaked and are in good body condition they are switched to a third table and fed strictly according to production. A fourth feeding table is used for the last 7 to 10 days before dry off to decreases concentrate fed in the robot gradually to zero. A second set of tables for first lactation heifers is often used to feed concentrate at levels that include a factor for growth. Other constraints on feed delivery in the robot include a preset feed speed, typically in the range of 0.45 to 0.90 lbs. per minute to ensure the cow consumes all the grain delivered and does not leave it for the next cow. The maximum increase or decrease per day can also be restricted to avoid sudden changes in the amount fed. If the cow does not have enough time to consume the amount of feed allocated the remainder is not fed and is reported as “rest feed”, some of which can be carried over to the following day.

An alternative for free traffic is to feed only forage in the bunk and feed all the concentrate according to production in the milking box. If the feed speed in the robot is set at 0.8 lbs per minute a high producing cow receiving 30 lbs. of concentrate needs 37.5 minutes to eat the allotted feed. If she is milked 3 times per day with a “box time” of 7 minutes she is only in the stall long enough to eat 16.8 lbs. of concentrate so the remaining amount is fed in computer controlled feeding stations located in the barn. Access to the feeding stations is offered only to cows that are ineligible for milking, either by the computer system or by physical location in a guided traffic barn, making “denied access” to this source of feed a further incentive to visit the milking box. Since eating rate is no longer a major concern when there are computer feeders, slower feed speeds and even mash feeds can be used successfully with this system.

In guided traffic systems, the reliance on concentrate in the robotic milking stall is thought to be less. Some guided traffic herds feed about 4.5 lbs. of concentrate in the milking box to all cows and feed a mixed ration in the bunk balanced close to the average production of the group, but many others use the same PMR feeding approach as with free traffic.

In a survey of nutritionists with robotic milking clients, (Salfer and Endres, 2016) report that palatability of the robot pellet and consistent mixing of the PMR were the biggest feeding factors for robotic milking success and they ranked these higher than consistent delivery and push up, PMR energy content and PMR starch content. The same survey indicated that herds that had tried feeding mash in the robots were dissatisfied with the results and with few exceptions had switched back to commercial pellets.

Each of the three feeding approaches described above has potential for economic advantage in specific situations. Limiting feed in the robot and balancing the bunk ration at a higher level allows for greater use of home grown grain stored on the farm, thereby avoiding transportation and pelleting costs in this part of the diet. Feeding only forage or a PMR balanced for a lower production level allows for individual feeding of concentrate according to production and stage of lactation. This results in higher forage lower grain diets for later lactation cows, making ration costs lower when energy and protein from grain costs more than nutrients from forage. The PMR and forage only bunk options make it possible to limit and gradually increase the total concentrate fed in the first three weeks of lactation, potentially resulting in lower incidence of metabolic disorders. A lower level of concentrate in the PMR may also reduce the likelihood of low producing late lactation cows gaining excessive weight.

FREE VS GUIDED TRAFFIC

The choice of guided vs. free traffic can have a substantial impact on feeding strategies as well as labor efficiency and cow comfort. Studies show the number of cows fetched can be decreased by forcing the cow to enter the robotic milking stall or an associated selection gate on route from the resting area to the feed manger or on her return from the manger to the resting area. Despite the fact that the cow has no alternatives, this is commonly referred to as “guided cow traffic” although many older studies refer to it as “forced cow traffic”. There are four common variations of “cow traffic” strategies used in robotic milking herds. (1) Free cow traffic, where cows can access feeding and resting areas of the barn and the robot with no restriction. (2) Guided cow traffic with one way gates blocking the route from the resting area to 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 them 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 return to the resting area through a one-way gate. (3) Guided cow traffic with “pre-selection” adds an entry lane where a sort gate directs cows eligible for milking to the “commitment pen” 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 guided traffic is a reversal of (3) 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.

One further distinction in routing options should be made and that pertains to the use of a “commitment pen” at the robot entrance which all cows must enter to access the robot and which they cannot leave until they have been milked. This pen is common to guided traffic barns. It is also used in some barns that do not restrict movement from the resting area to the feeding area and back. In these barns it is used to force fetched cows to go to the robot and as a way to sort cows to different areas of the barn after milking. While routing that allows cows access to both the resting and feeding areas would traditionally be considered free traffic, the use of a commitment pen restricts cow movement. A preferable way to direct fetched cows to the robot is with a “split entry fetch pen” that is exclusively used by fetched cows.

Older studies (Hoogeveen et. al., 1998; Van’t Land et. al., 2000) report more frequent milking but fewer visits to the manger and less resting time with guided traffic. Harms et. al. (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, guided and guided with pre-select traffic, respectively. The number of meals was higher at 8.9 with free cow traffic, than with either guided or guided with pre-select, where cows consumed 6.6 and 7.4 meals, respectively. Forage intake decreased when cows were switched to guided traffic and went back up in the guided with the pre-select phase. Hermans et. al. (2003) reported that cows with free access to forage in the manger spent more time eating and less time standing in freestalls. Thune et. al. (2002) reported 1.98, 2.56 and 2.39 milkings, and 12.07, 3.86, and 6.46 feeding periods with free, guided and guided 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 guided traffic. Timid cows waited as long as 4 hours per day for milking because, they are directed into the commitment pen on route to or from the manger, but higher ranking cows continually beat them into the robot, leaving them trapped in the commitment pen for several hours. From a cow comfort perspective this is highly undesirable and may lead to poor metabolic health and increased lameness, eventually leading to a further deterioration in visiting behaviour.

On Ontario farms with guided 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 ± 0.44. This is many meals fewer than the 10 to 12 expected with free access to the manger. Fewer meals are associated with lower dry matter intake and guided 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 guided 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 alerts the herdsman to her plight. Faced with the choice of starvation or milking this cow is more likely to go unnoticed in a guided traffic setting.

In a comparison of free traffic and milk first guided traffic systems (Bach et. al., 2009), cows were fed a partial mixed ration and up to 3 Kg of concentrate in a VMS (DeLaval, Tumba, Sweden) 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. A large difference in the number of fetched milkings suggest that in a commercial setting labor savings with this system would favor use of guided traffic.

A recent study (Tremblay 2016) analyzed data from 635 North American dairy farms with Lely Astronaut AMS (Lely Industries N.V., Maasluis, the Netherlands) and reported that milk production per cow and milk production per robot were 2.4 lbs and 148 lbs per day higher with free traffic than with guided traffic.

Concerning the choice between feed first and milk first guided traffic, observations of producers, nutritionists and researchers (Salfer and Endres 2016) suggest that typical US diets that are relatively high in energy density work better with milk first traffic, since the desire for feed seems to have a greater influence on activity than the need for rest. From a cow comfort perspective restricting the cows movement from the rest area, where she needs to spend 12 to 14 hours per day, rather than from the feeding area, where the daily time budget for eating is just 4 to 5 hours, is the more logical choice in all cases. In nearly all situations option (2) above (guided traffic with no preselection), or option (4) (feed first guided traffic) are inappropriate and the choice of traffic systems comes down to free traffic or milk first guided traffic with pre-selection.

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. (Rodenburg 2012) There are also numerous examples of guided 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 guided traffic the cows suffer the consequences with lower feed intake, and longer waiting times. Since problems are more likely to be resolved quickly when the dairyman suffers, free cow traffic is the preferred management system. The voluntary aspect of robotic milking is increasingly linked to a positive cow comfort and welfare consumer image for robotic milking and this is a further reason to opt for the free traffic approach.

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)	Treatment 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
Voluntary milkings	1.7	2.4	0.06	<0.001
PMR intake (lbs. DMI)	41.0	38.8	1.34	0.24
No. of meal of PMR	10.1	6.6	0.30	<0.001
Concentrate intake (lbs.)	5.5	5.5	0.09	0.99
Milk production (lbs.)	65.7	68.1	1.74	0.32
Milk fat content (%)	3.65	3.44	0.078	0.06
Milk protein content (%)	3.38	3.31	0.022	0.05

USING FEED AS AN ENTICER FOR VOLUNTARY MILKING

Early research showed that without a feed incentive voluntary attendance at the milking stall is poor and highly variable. Feeding concentrate in the milking box, or denying access to feed at the manger for cows eligible for milking until after they are milked (guided traffic) improves attendance at the milking stall. Although all commercial robotic systems currently offer concentrate in the milking box, and some use a form of guided cow traffic, failure of some cows to attend voluntarily remains a concern. The number of cows which must be fetched has been reported to be as low as 6% (Van't Land, 2000) on Dutch farms and as high as 19% on commercial farms in Ontario (Rodenburg and Wheeler, 2002). In recent years design improvements that have made the cow more comfortable in the milking stall, such as more space and the removal of the butt plate and indexed manger in some models has improved milking frequency and reduced the number of cows fetched. In systems that still use these space limiting devices, adjusting them properly is a factor in improving voluntary attendance.

The concentrate fed in the milking stall is the "candy" that attracts the cow to come to the stall frequently for milking. More frequent milking shortens milking intervals and decreases variation in milking interval. Both of these outcomes increase milk production. Having fewer cows to fetch reduces labor for the operator.

The importance of feeding palatable concentrate in the milking stall, is illustrated by a case study on one Ontario farm. (Rodenburg and Wheeler, 2002) Initially, a low cost pellet formulated with lower palatability ingredients including gluten meal, canola and tallow was fed. Poor pellet strength caused a buildup of fines in the bottom of the feeders. A stronger pellet of high palatability containing 3 (vs. 0) % molasses and 96 (vs. 65) % high palatability ingredients was substituted. Voluntary visits increased from 3.40 to 4.04, and voluntary milkings from 1.72 to 2.06 per cow per day. Canadian robotic milking system owners describe cows that they have to fetch for milking, as "lazy" when there is no clear reason, such as inexperience, clinical mastitis or lameness, for not attending voluntarily. Using this definition, "lazy milkings" and "lazy cows" declined from 27.3% and 16.0% to 12.7% and 7.1% respectively, when the stronger pellet replaced the weaker one. In another study (Rodenburg, Focker and Hand, 2004) we formulated a concentrate for what we thought was maximum palatability. Ingredients included corn, soya hulls, wheat shorts, barley, bakery meal, soybean meal, corn distillers, extruded soy meal, wet molasses, animal vegetable fat blend, vitamin mineral premix, sodium bicarbonate, salt, pellet binder and fenugreek flavour. In comparisons to commercial concentrates on four farms, in trials with three consecutive 15-day crossover/switchback feeding periods we found that visits (3.95 vs. 4.80) and milkings (2.69 vs. 2.81) were fewer ($p <.05$) for the experimental pellet when compared to a stronger commercial pellet (shear strength of 91.2 vs. 96.0 pdi) in trial 1. In trial 2, the experimental pellet was compared to a different commercial product of equal shear strength and in this trial attendance was unaffected. In trial 3, conducted in the same herd as trial 2, the pellet was reformulated to exclude all mineral ingredients, but no difference in attendance was found. In trial 4 a mixture of 50% commercial pellets and 50% high moisture corn was compared to our experimental pellet, adjusted to make it isonitrogenous with the control. As in trial 1, number of visits (3.06 vs. 3.33) and milkings (2.34 vs. 2.49) were lower ($p< 0.05$) for the experimental pellet. In this trial shear strength of the experimental pellet was weaker, 86.9 pdi vs. 97.7 pdi, than the commercial pellet and there was evidence of fines in the feeder when it was fed. One other herd volunteered to test a mixture of 49 % dried corn distillers, 49% cracked corn, 2% molasses and 0.1% flavoring agent fed in a mash form, but during a 6 day feeding period the number of visits decreased from 3.93 to 3.57, and number of milkings from 2.50 to 2.35. Milk production declined from 57.2 to 53.6 lbs and since this was unacceptable on a commercial farm, the trial was discontinued. These studies clearly demonstrate that the concentrate fed in the robot should be pelleted and pellets should be of high quality and free from fines. Feed delivery systems should be designed to minimize pellet breakdown during handling.

Danish researchers (Madsen et. al., 2010) compared 7 pellet formulations and found substantial differences in the number of visits, the number of milkings, the number of fetch cows and in milk production, linked to the ingredients used in the pelleted concentrates. Results are summarized in table 2. As illustrated cows preferred a barley and oats combination, followed by a wheat based concentrate. Corn was less palatable and a fat enriched pellet and one based on dried grass resulted in significantly fewer visits and lower milk production.

Table 2. (Madsen et. al.) Effect of concentrate formulation on robotic milking behavior and milk production. Effect of test feed expressed as test feed minus standard.

Concentrate (per cow/day)	**Standard (mean)**	**Barley**	**Wheat**	**Barley/Oats**	**Corn**	**Fat Rich**	**Dried Grass**
Milkings	2.96	-0.03	0.17	0.35**	0.02	-0.36*	-0.93***
Refusals	2.09	-0.05	0.44	1.87	0.31	-0.39	-1.16
Fetchings	0.026	0.028	0.019	0.009	0.50	0.042	0.17
Lbs. Milk	57.5	0.22	3.53*	2.65	0.44	-1.98	-9.04***

** = p <0.01
*** = p <0.001

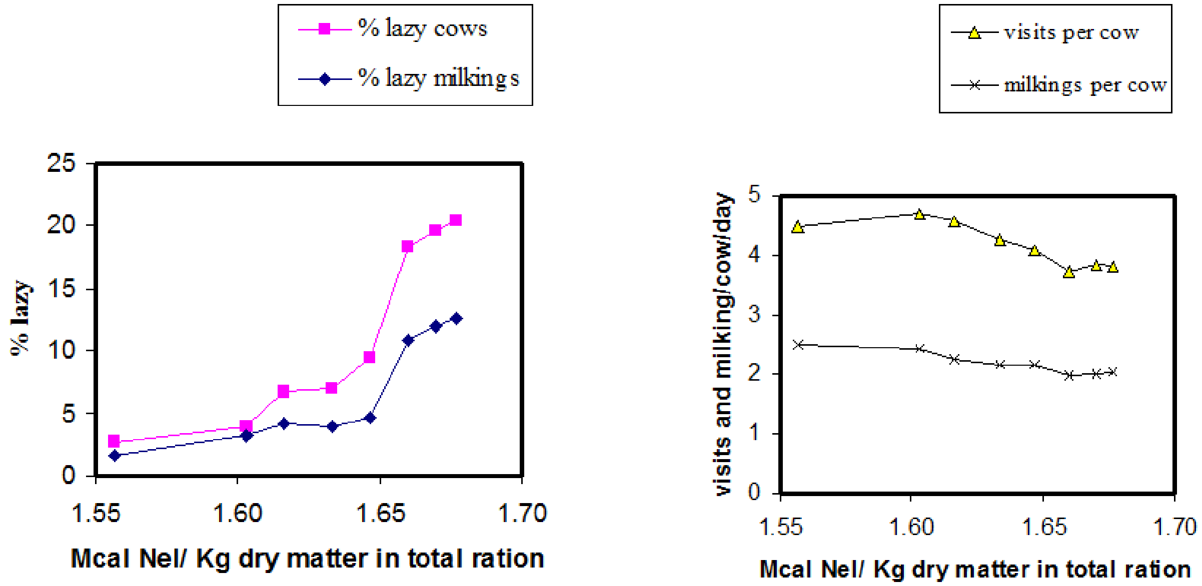
Including 150 ppm of a commercial flavoring agent with fenugreek and vanilla and 500 ppm of a sweetening agent in the robot concentrate increased milk production and passes through the preselection gate but not milking frequency in one trial (Migliorati et.al., 2005) and 4% higher milking frequency and 3.5% higher production in another trial (Migliorati et. al. 2009) with guided cow traffic, so this seems to offer a small but positive effect.

Halchmi et. al. (2009) compared feeding a high starch pellet (53% starchy grains) with a low starch pellet, (25% starchy grains with soy hulls and corn gluten) and found no difference in milking frequency but production was higher with the lower starch pellet.

The opportunity to reduce the cost of concentrate fed in the robot by replacing the high quality pellet with mash feeds is often put forward in the field as an advantage of guided traffic. A recent Canadian study (Penner 2017) substituted 5.5 lbs per day of steam rolled barley for an equal amount of pelleted barley for 8 late lactation cows. Although none of the differences were statistically significant concentrate intake trended lower (5.4 vs. 5.5 lbs. *P* = 0.14) milking frequency trended lower (3.29 vs. 3.55 *P* = 0.27) and milk yield trended lower (70.3 vs. 81.8 lbs. *P* = 0.17). This suggests that regardless of the traffic system chosen the feed in the robot should be a high quality high strength commercial pellet.

Field observations on Canadian farms (Rodenburg and Wheeler 2002) suggest that diets with a high energy density are correlated with fewer milkings and more fetch cows as illustrated in figure 1. “Lazy cows and lazy milkings” are defined as fetched cows and fetching events for which the herdsperson had no clear explanation, such as no experience, estrus, clinically lame, or clinical mastitis. Since meeting the cows nutrient requirements remains the first priority feeding insufficient energy to improve traffic is not an option, but many nutritionists and producers in the field speculate that sourcing energy from digestable fibre in the PMR to make starch in the robot concentrate of greater interest is advisable (Salver and Endres 2016)

Fig. 1 (Rodenburg and Wheeler, 2002) Energy Level in Diet Dry Matter and Milking Behavior .



The amount of pellets fed in the robotic milking stall appears to have less influence on visiting behavior than the composition and pellet strength. Feeding 8.8 lbs. of concentrate plus 0.16 lbs. per lb. of milk produced vs. 2.2 lbs. plus 0.16 lbs. per lb. of milk did not alter milking frequency or production in a guided traffic setting. (Migliorati 2005). Halachmi et. al. (2005) compared milking frequency when concentrate intake was limited to 2.6 lbs. per milking vs. offering a maximum of 15 lbs. per day. The actual difference in average robot concentrate in this trial was 7.7 lbs. per day for the low group and 11 lbs. for the high group and milking frequency was not different. Feeding 6.6 or 17.6 lbs. of pellets in the robotic milking stall to cows fed a high corn silage diet at the manger did not result in any difference in the number of cows requiring fetching but and although there was a trend to more milkings (2.8 vs 2.6 $P = 0.13$) the difference was not statistically significant. (Bach et. al. 2007a). Quantitatively, for every 1 lb. increase in concentrate fed there was a 1.14 lb. decrease in PMR intake and no change in milk production. In this study the ration fed was quite energy dense, and it is likely that this reduced the attraction offered by higher levels of concentrate in the milking stall. Recent Canadian studies, as yet unpublished but presented at a conference (Penner et.al. 2017) found that in a feed first guided traffic setting, feeding 1.1 lbs. of concentrate in the robot combined with a high concentrate PMR resulted in more frequent milking and higher milk yield than feeding 11 lbs. of concentrate in the robot with a lower energy PMR formulated so the target intake would be isocaloric. Feeding 11 lbs of grain separate from the PMR depressed total dry matter intake from 56.6 lbs. to 51.8 lbs. Results are summarized in table 3.

Table 3. (Penner et. al.) Effect of providing a low energy PMR (LE-PMR) and high robot concentrate allowance vs a high energy PMR (HE-PMR) and low robot concentrate allowance in a guided traffic setting.

Parameter (lbs./cow/day)	LE-PMR	HE-PMR	SEM	*P*-value
Total DMI,	51.8	56.6	1.23	0.13
Robot concentrate DMI	11.0	1.1	0.1	<0.001
PMR DMI	40.8	55.3	1.18	0.002
Milk yield	74.1	80.0	2.95	0.09
Milkings (per day)	2.82	3.27	0.19	0.09

In a subsequent study they evaluated whether the energy density of the PMR and the amount of concentrate offered in the milking stall interact to affect dry matter intake, milk yield and composition and ruminal fermentation. Diets were formulated to contain a PMR with either low energy density (forage to concentrate ratio of 64:36) or high energy (forage to concentrate ratio of 44:56) Within each PMR cows were either provided with a low robot concentrate provision (4.4 lbs. dry matter per day) or high robot concentrate provision of 13.2 lbs. dry matter per day. The low PMR/high robot diet and high PMR/low robot diet contained the same dietary energy density. Results are shown in table 4. Total dry matter intake was the same across all 4 treatments, but cows receiving the higher level of concentrate in the robot ate 9.2 lbs. more concentrate in the robot and 7.7 lbs. less PMR. Every 1 lb. increase in concentrate fed outside the PMR resulted in 0.85 lb less PMR intake. In this trial cows fed more concentrate in the robot had a higher milking frequency (3.7 vs 3.5 milkings per day) and a tendency to greater milk production (86.4 vs. 83.6 lbs. per day *P* = 0.10). Milk fat percentage trended lower with more robot concentrate and milk fat yield did not differ among treatments.

Table 4. (Penner et. al.) Effect of providing a low energy PMR (LE-PMR) and high robot concentrate allowance vs a high energy PMR (HE-PMR) and low robot concentrate allowance in a guided traffic setting.

	Low PMR energy density		High PMR energy density			*P* value		
Variable	Low robot	High robot	low robot	High robot	SEM	PMR	robot	PMR x robot
DMI lbs./day	58.9	60.6	60.0	51.1	2.09	0.18	0.46	0.68
PMR lbs./day	54.2	46.9	55.6	47.6	1.85	0.39	<0.01	0.85
Robot lbs./day	4.4	13.9	4.4	13.4	0.48	0.65	<0.01	0.34
Milk lbs./day	82.4	84.7	84.9	88.2	4.70	0.10	0.10	0.73
Fat %	3.70	3.55	3.57	3.46	0.17	0.11	0.09	0.78
Milkings/day	3.56	3.74	3.52	3.67	0.144	0.46	0.02	0.75

The studies in table 3 and 4 are conducted with guided traffic and these results are not likely applicable to free traffic where concentrate in the robot is the only motivation for milking. On commercial dairies many of the fetch cows are late lactation low producers that are already receiving more energy than they need from the PMR and that have limited interest in the concentrate in the robot.

Since feed speed, which is limited based on eating rate, limits the amount of concentrate a cow can eat in the robot, and since milking frequency and box time vary quite widely among cows, research studies that offer high levels of concentrate in the robot (Bach et.al. 2007a, Penner et. al. 2017) report that concentrate intake and hence the total ration composition are more variable when a higher percentage of the concentrate is fed in the robot. Most of the robotic milking systems report concentrate that is not offered due to lack of box time, as ‘rest feed”. If that feed was offered because the cow required it, large amounts of rest feed reported for healthy cows, especially healthy cows more than 50 to 60 days in milk, are a strong indication that the energy level in the PMR should be increased and the amount of concentrate in the robot should be decreased.

But on the other hand, if nutrients from home grown forage are cheaper than nutrients from concentrate, feeding more of the concentrate in the robot makes it possible to feed a higher forage diet to lower producing cows resulting in reduced feed cost and less risk of over conditioning these cows. Computer software that gradually adjusts and tests concentrate feeding levels to determine the optimum amount of concentrate for individual cows is in use and has been demonstrated to reduce feed costs, (Andre et. al. 2009, VanHolder et. al. 2010, Wesselink, 2011) especially where concentrate costs are high relative to forage costs. This “dynamic feeding” approach is an example of how individual management made possible by robotic milking can increase profitability.

Based on the above research, the decision of how much of the concentrate to put in the robot vs in the PMR has great potential to impact on the number of fetch cows, milking frequency, milk production and feed costs, but the research to date does not offer very clear answers. With higher amounts of concentrate in the robot and less in the PMR, there is a tendency to more frequent milking, especially with free traffic, although pellet quality seems to be more important than quantity. Less grain in the PMR may also decrease the need for fetching late lactation cows, and by feeding concentrate according to production it has the potential to reduce feed costs. Less grain in the PMR also allows for more gradual increases in grain feeding in early lactation perhaps promoting better rumen health, and it reduces the risk of over feeding late lactation cows. The advantages of including more of the concentrate in the PMR include not having the expense of pelleting it and avoiding the variation in diet composition associated with rest feed.

Although I am not a nutritionist, the benefit of feeding cows individually according to production appeals to me, so I am inclined to encourage the use of the current recommendations to balance the PMR for a production level 17 lbs. below the group average and feed robot pellets according to production and stage of lactation for cows above that production level. This approach will be successful if the pellet quality is high and if the feed speed can be pushed up toward 0.8 to 1.0 lb. per minute. Monitor the robot manger to make sure most cows are cleaning this up. If higher producing cows are milked frequently they will get the concentrate they need and low producers will not be overfed. Monitor rest feed to make sure the majority of cows are getting the ration you have formulated for them. If there are cows past 50 days in milk with a substantial amount of rest feed adjustments in the forage to concentrate ratio and robot feeding levels may be warranted.

PRACTICAL TIPS FOR FEEDING ROBOT PELLETS

While pellet quality is primarily the responsibility of the feed supplier, proper design of the storage and delivery system on the farm can also be a factor. Ideally, having two bins for each feed type allows for the complete clean out of the bin so there is no buildup of stale or damaged feed. Flex augers should be of limited length with moderate bends preferably in the same direction the augur turns. “Chain and paddle style augurs generally do less damage to pellets and may be preferred if pellet quality is going to be less than ideal. Last but not least, managers of robotic milking systems need to ensure that the pelleted concentrate is actually dispensed accurately. As a checkpoint to make sure there are pellets flowing it is a good idea to use clear plastic hoppers on the above the robots for a simple visual inspection that there is feed there. Making sure pellets are flowing should also be part of the daily robot cleaning and care routine. The pellet delivery system should also be calibrated every few weeks.

GROUPING COWS IN ROBOTIC MILKING HERDS

Nearly all robotic milking herds are made up of groups of cows at all stages of lactation in order to balance the number of stalls and total milking time with the time available for milking. Milk production per cow and per robot has been reported to be slightly higher with 2 or 3 milking stalls per group than with 1 stall. (Tremblay et. al. 2016, Heurkens 2015). Grouping by age and size to allow for a range in free stall sizes that optimize comfort and cleanliness is a common practice in larger herds. In robotic milking, a well established social order within the group is thought to be of greater importance than with parlor milking because cows must compete for robot access. Hence group changes in mid lactation are not commonly used or recommended. It has become common to provide a low stress area for fresh cows with access to a milking robot. This would be a dedicated robot in large herds, and one that is shared with another group in smaller herds. It is thought that cows should be moved out of this group to the main herd no later than 4 days to 3 weeks after calving. While the present argument for groups with a wide range of calving dates and production levels is to utilize robot capacity uniformly, the most stable social group would be a group of cows at the same stage of lactation. This is currently not done because it makes uniform robot utilization impossible to achieve. But if stable social groups are thought to be very beneficial, research should be conducted to determine if benefits are sufficient to recover the additional cost of underutilization of the robots in late lactation.

PASTURE BASED AUTOMATIC MILKING SYSTEMS

Since grazing cows are further away from the robots it is more difficult to achieve evenly distributed milkings with a grazing-based robotic milking system than it is with housed cows. Extensive research conducted through the FutureDairy project (http://futuredairy.com.au/) in Australia has helped develop robotic milking management practices that are applicable to pasture based dairy production systems. Farmers adopting robotic milking in grazing applications generally operate with a system of voluntary milking and guided cow traffic using concentrate in the robot as well as strategic access to fresh pasture after milking. When pasture is in short supply it also includes supplementary forage fed at pasture or on a feedpad or in the barn. The goal is to use these incentives strategically to ensure target milking frequencies and system utilisation are achieved. Automatic sort gates are programmed to direct cows into the commitment pen when they are eligible for milking or back to pasture if they are not, and after milking cows return to pasture. At two to four scheduled times of the day, the exit to pasture directs cows to a fresh pasture allocation. In a research study (Lyons et. al, 2013), cows that were given access to new pasture every 12 hours in a 2 way grazing scheme were milked an average of 1.52 + 0.41 times per day and produced 46.9 + 16.7 lbs. of milk per day.

When they were switched to a protocol which sent them to new pasture every 8 hours in a 3 way grazing scheme, total daily waiting time in the commitment pen and total walking distance increased. Despite this, the additional fresh feed incentive of 3 way grazing reduced milking interval by 31%, increased milking frequency by 40% and increased production per cow and total output from the system by 20%. With 3 way grazing a steadier flow of cows on to new pasture reduces the incidence of both very short and very long milking intervals. Accurate pasture allocation is critical to achieving reliable and consistent voluntary cow movement. To ensure that cows are motivated to move around any robotic milking pasture-based farm system they need to deplete a given pasture allocation so they have a motivation to move through the system in search of more pasture. This accurate pasture allocation should not be confused with under-feeding. Cows don’t have to be underfed to achieve the required level of motivation. If feed is consistently over allocated, cows will stay in the pasture longer, resulting in reduced milking frequency and a drop in milk production. Under-allocation will increase milking frequency but reduce feed intake, milk harvesting efficiency (lbs. harvested per minute at the robot) and overall milk production. When feed is under allocated cows tend to loiter in the milking area waiting for the next pasture to become available, resulting in reduced system efficiency. During periods of supplementary feeding, offering supplementary feed on a feedpad or in the barn after milking results in greater milking frequency, shorter milking intervals and more time spent on pasture than offering feed before milking. (Lyons et. al. 2013a). Feeding cows before milking may still be a useful strategy to encourage cows to spend more time on the feedpad or in the barn, during periods of high supplementary feeding or at times when pastures are waterlogged. Ideally the feedpad should be located and gated so it can be used before or after milking in the robot. This would also allow some priority selection. For example, a cow that came to the dairy and was overdue for milking could be offered feed after milking; while a cow that has only recently been granted milking permission (i.e. a relatively short interval since its previous milking) could be offered feed prior to milking. This type of strategy is likely to enhance milk harvesting efficiency by further reducing extremely short and long milking intervals.

A layout for a milking area with appropriate gating for three way grazing and use of a feedpad is shown as Figure 1. In situations that combine grazing with robotic milking and winter housing in barns, the robotic milking stalls are more likely to be located in the individual barns rather than in a central location as in figure 1. In this case, additional selection gates are needed at the barn entrances to allow access by cows to their specific barn and robot group. This access would be from a common collection yard with routing similar to figure 1 to the pasture areas. This facilitates housing cows in 120 or 180 cow groups in winter while allowing all cows access to a common pasture rotation while grazing.

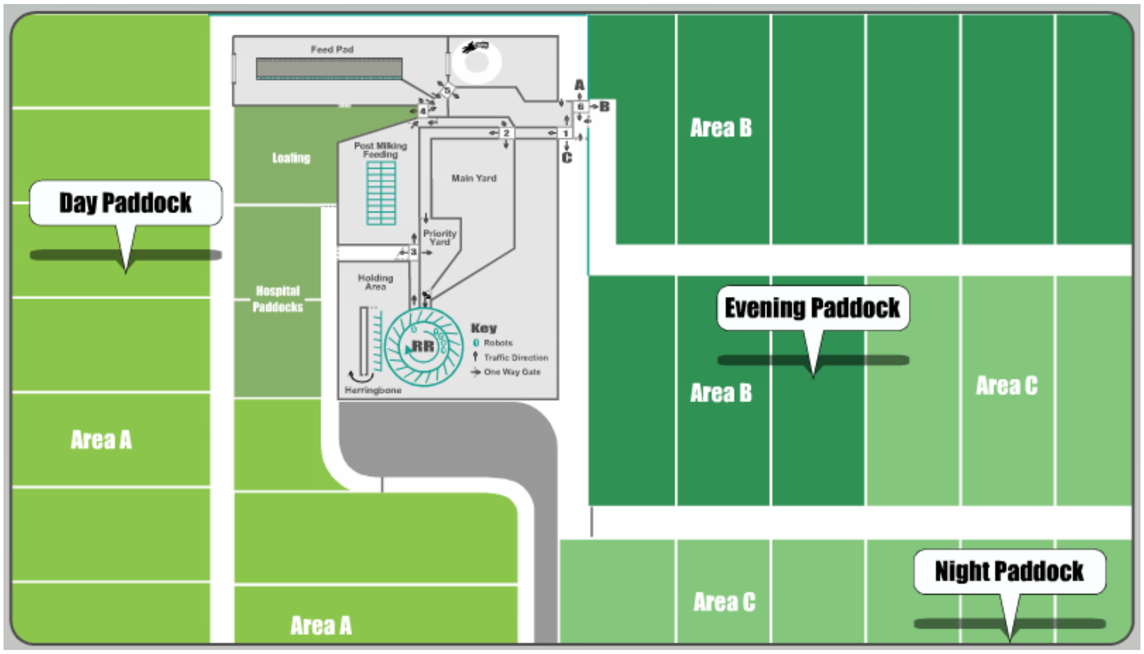


Figure 1a: A pasture farm set up for three way grazing. Cows in this diagram are milked in a robotic rotary but the layout would be identical with a cluster of single box robots. Two laneway directions provide access to three pasture breaks per day provided one laneway is split. Each paddock is subdivided with electric fence to provide 8 hours grazing for the herd.

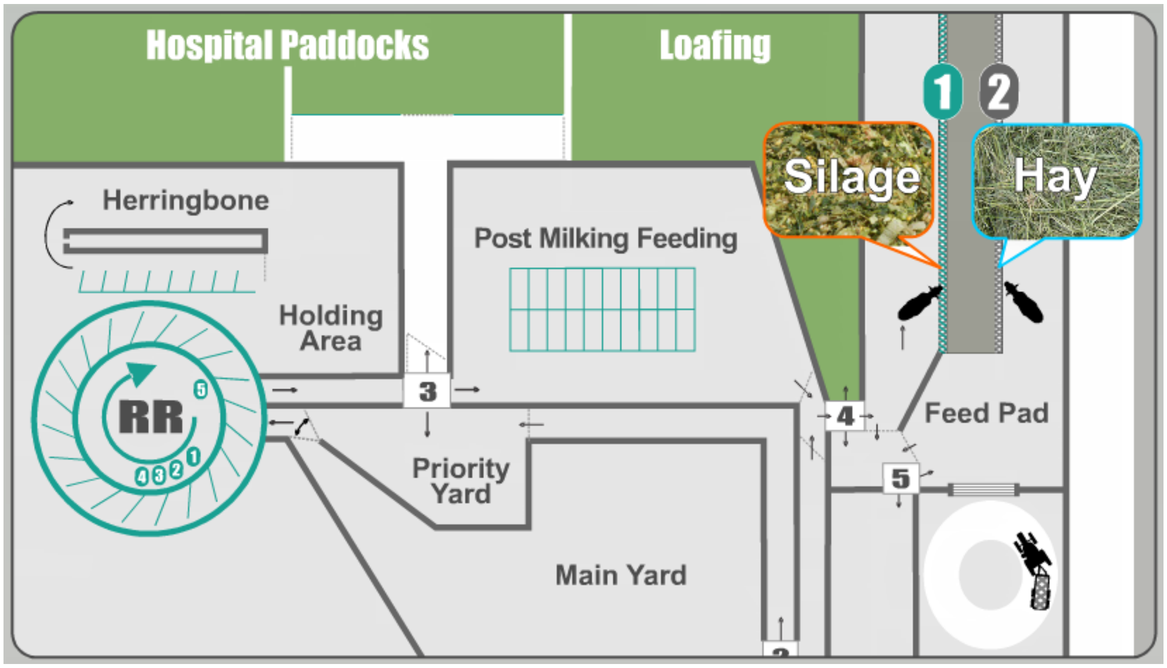


Figure 1b: a detailed sketch of the milking and handling area, Figure 1a, 1b were provided by “Future Dairy, Camden, New South Wales, Australia.

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