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AUTOMATIC AND FREQUENCY-PROGRAMMABLE SYSTEMS FOR FEEDING TMR: STATE OF THE ART AND AVAILABLE TECHNOLOGIES

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ABSTRACT Feeding Total Mixed Rations (TMR) or Partial Mixed Ration (PMR) has become a common practice for dairy cows as a result of the benefits for the animals and the labour savings for farmers. Characteristic for this feeding system are the – trailed or self propelled – man-operated mechanical mixers. Besides the advantages of the TMR technique, it has the same drawback as most traditional ad libitum feeding systems that the discharge of feed is limited to once, maximum twice a day. During the last 3-5 years, technologies for automatically feeding cows with TMR or PMR have grown in popularity. More than 15 manufacturers are working worldwide on different designs for automatic TMR/PMR feeding systems (AFS) while an estimated 300-400 farms have adopted this technology, mostly located in Northern Europe, Canada and Japan. The different manufacturers offer a wide range of technical solutions. Some of the most important aspects that characterize these systems include the possibility of a variable frequency drive to modulate the ration, to control the feeding times, to stimulate the cow activity and to manage the composition of the total daily ration with the objective to control the feed intake. Management possibilities and work quality seem to be strongly affected by available technical solutions. This paper provides a proposal for the classification of different AFS's and suggestions for future research on feeding strategies; it also focuses on daily feeding frequency and the time intervals between distributions.

Keywords: Dairy cows, Feeding system, TMR, Feeding automation.

INTRODUCTION Feeding cows in modern dairy farms is important for both an economic and technologic point of view. The cost and the larger quantity of feeds to be handled for the larger and higher yielding herds, stimulate interest in efficient utilization of feedstuffs. An example is the TMR technique that provides balanced nutrients over time. Over the last 15-20 years, this feeding method – with the trailed or self propelled feed mixers – has become popular (Barmore, 2002). More recently, automatic feeding systems (AFS) for TMR have been developed by research centers (Kazumoto, 1999; Tamaki, 2002) and by manufacturers (Hollander *et al.*, 2005).

These AFS's are based on either existing technologies for single feedstuff automated distribution (concentrates, silages, forages) or on complete new concepts. The integration of AFS's in the lay-out of new or existing barns raises questions with respect to the location and capacity of the components of an AFS. Pompe *et al.* (2004) proposed a discrete-event simulation model to generate answers such questions. The increased utilization of these systems at farm level during the last 3-5 years, has stimulated their in-field assessments (Gjødesen, 2007) and industrial production and development. At present 16 manufacturers are known to have developed different automatic operating designs (Nydegger and Grothmann, 2009) and an estimated 300-400 farms – for the most part located in North Europe, Canada and Japan – have adopted this type of mechanization.

One of the features of an AFS for TMR includes the possibility to increase the daily frequency of feeding from 1 up to 15 cycles per day. This provides potential to stimulate cow feeding activity and dry matter intake and to promote the natural feeding behaviour of more meals per day. Azizi *et al.* (2009) found meal frequencies for cows of 7-9 meals per day, meal durations of 36-38 minutes/meal and meal sizes of 2-3.5 kg per meal. These results are similar to those of other researchers, but cow and management related factors, and also the definition of the meal criteria, affect the magnitude of these results. De Vries *et al.* (2005) investigated the influence of the frequency of daily feed delivery on cow behaviour and concluded that frequent delivery of feed improves access to feed for all cows, particularly during peak feeding periods when fresh feed is provided, and reduces the amount of feed sorting. Mäntysaari *et al.* (2006) and Pompe *et al.* (2007) found that frequent supply of fresh roughage decreased the peaks in cow visits to the feeding places that are typical for conventional feeding systems. DeVries and von Keyserlingk (2005) found that delivery of the feed 6 hours after milking increased the total daily feeding times of the cows with 12.5% compared to the situation of feed delivery at the time of milking.

This paper aims to provide a review of the mechanical designs for AFS that are currently available on the market, to propose a classification of these systems and to formulate feeding strategies and management that utilize AFS to its full potential.

The study focuses on AFS's for free-stall housing, AFS's for other housing systems are not considered.

MATERIALS AND METHODS The manufacturers presently involved in developing AFS technologies were identified by reviewing commercial sources (agricultural expositions and manufacturer's leaflets). We developed an overview of the various design concepts based on technical information provided by the producers and the existing literature (Hollander *et al.*, 2005; Gjødesen, 2007; Nydegger and Grothmann, 2009). We carried out a survey at 12 Dutch dairy farms using different design of AFS to assess their feeding strategies and management systems.

To identify the various design options for AFS's we applied the engineering design methodology of morphological charts (Cross, 2008) and we outlined specific working characteristics with the aid of process charts according to ASME standard 101. We formulated feeding strategies and management options by matching the design concepts for AFS's to the information on cow feeding behaviour from the literature.

Table 1. Manufacturers* involved in AFS development and production for TMR in free-stall housing.

Alph. order	Make	Model		Feeding method	Country
1	Agro Contact	SM 2000 MS 3000		Group	Canada
2	Agro X	One2Feed		Group	Denmark
3	Airablo	R.T.M.i.		Group	Canada
4	Cormall **	Multimix MTX	a. Conveyor b. Multi-feeder	Group	Denmark
5	De Laval	Optimat		Group	Sweden
6	Hetwin	Fütterungsroboter		Group	Austria
7	Lely **	Atlantis		Individual	The Netherlands
8	Mullerup	Mix feeder		Group	Denmark
9	Pellon	a. Mixing device b. Filling device	a. Conveyor b. Feeder Robot	Group	Finland
10	Rioh	Sputnic		Group	Denmark
11	Rovibec	Dec DP Dec SR		Group	Canada
12	Schauer **	Transfeed Dec (Rovibec system)		Group	Austria
13	Schuitemaker	Innovado		Group	The Netherland
14	Trioliet	Triomatic		Group	The Netherland
15	ValMetal	D.A.F.		Group	Canada
16	Wasserbauer	MixMeister		Group	Austria

* The authors apologize for possible and involuntary oversights. Mention of trade names is for the benefit of the reader and does not constitute endorsement by the authors over other products not mentioned.

** Also agreement with other manufacturers to widening the market options.

RESULTS Overview of currently available AFS's An overview of the currently available AFS's is reported in Table 1. The review of the relevant technical data shows a range of design concepts including preindustrial prototypes and commercial models that can feed cows with TMR or PMR, both individually and per group. These systems can be stationary or mobile with different automatic feeding methods. Based on the farm survey, feeding strategies and feeding management are outlined in the following.

Characteristics of Automatic Feeding methods A morphological chart with the different mechanized functions involved in TMR/PMR preparation with the solutions to automatically accomplish these functions is shown in Figure 1. The figure contains the design line (the dashed line) for the AFS as developed by Agro X, Mullerup, Pellon – and is intended for illustration purposes only.

A first distinction between automatic TMR feeding methods can be based on the possibility of feeding cows individually or per group.

Individual feeding in free stall-housing This option provides the possibility to feed cows with different components, balanced to fit the specific requirements of each animal. The only system at present developed is the Atlantis: a stationary system manufactured by Lely at its prototype level. The operator fills a temporary storage with the various feedstuffs, from where a trolley automatically collects and transports small loads of the feedstuffs along an overhead rail to small hoppers. From there the system prepares specific rations on demand of the cows by dropping the different ingredients in the individual feeding troughs in small-sized quantities (total amount ~1 kg). The small quantities prevent cows to select single feeds.



















































Store feed	Unload feed	Transport feed	Temporarily store feed	Weigh feed	Mix feeds	Deliver ration	Provide rations to cow(s)
							
							
							
							
							
							
							
							
							
							
							

Figure 1. Morphologic chart for TMR preparation and distribution. An example is provided for function and sub function definition in order to define possible automatic methods (Kosse, 2005; adapted).

Group feeding The majority of the AFS's developed at present belong to this group of automatic TMR feeding method: the cows are fed with diets balanced for the average requirements of the group and not with individually balanced rations. Combinations are possible with self feeder concentrate dispensers placed either in the milking parlour/milking robots or elsewhere in the barn.

AFS's can be classified based on their propelling mode (stationary or mobile systems) and on the way they process the ration (stationary mixer or mobile mixer wagon).

Stationary systems These models contain metallic or rubber conveyor belts (Agro Contact, Cormall, Pellon, Rovibec, Valmetal) and are based on known technologies for roughage distribution used, in particular, where space was limited. These systems have evolved more and more towards TMR feeding, thanks to the introduction of stationary mixers that generally provide one ration each. The ration is transported and/or distributed at a preset time by conveyors that either operate as feeding table or drop the feed in the manger from above.

Mobile systems based on feeder wagons These systems (i.e. Cormall Multi-feeder, De Laval Optimat, Pellon Mixing device plus Feeder robot, Schauer/Rovibec SR, Rioh Sputnik) are based on one or more stationary mixer(s) provided with scales, which also operate as temporary, daily storage. The operator has to fill the mixer(s) from farm storages with the daily quantity of components both by means of tractor loaders for roughages and silo unloaders for concentrates. The mixing system can be equipped with blades to enable chopping long stemmed products (hay, straw) or can be

combined with pre-chopping units. The TMR that is prepared remains in the mixer over the course of the day from which it is automatically transferred 1-15 times per day to the feeder wagon. This operation can be achieved by means of conventional conveyors (i.e. De Laval, Pellon) or directly from the mixer(s) (i.e. Cormall, Schauer/Rovibec SR). These systems need one mixer for each TMR to prepare; alternatives (De Laval) include mechanic temporary storages for roughages - filled every 1-3 days by the operator - to automatically load the stationary mixer with the relevant components thus allowing preparation of different rations with the same mixing unit. Every TMR prepared is then distributed at preset intervals by means of a small-volume, high-rate feeder wagon that automatically recognizes which TMR has to be distributed and which group of animals has to be fed. Most feeder wagons are rail-guided and electric powered by means of a battery rank on board. The wheeled, self-propelled feeder wagon (Cormall) is guided by laser sensors and sensors on the floor. The nominal volume of automatic feeder wagons is generally lower compared to conventional tractor trailed ones and range from 2.5 to 4.3 m³ thus allowing stables designed or restructured with feeding alleys that are narrower (2.2 - 3.5 m wide) than conventional ones. More technical details of these systems are shown in Table 2.

Mobile systems based on feeder mixers These systems consist of a temporary storage for components that automatically and at preset intervals fill a mobile mixer wagon. The temporary storages generally consist of rectangular containers, with volumes ranging from 7 to 50 m³, provided with unloading devices. The containers are usually fixed, aligned near the stable, but some are mobile (Agro Contact, Agro X, Wasserbauer). They are mechanically filled by the operator from the conventional farm storages and are intended to be labour-saving because they only need to be refilled every two-three days. The containers that can automatically load the mixer wagon can have different designs. Some models are shaped in order to directly fill the wagon (Cormall, Hetwin, Pellon, Rovibec DP) thanks to an overhead side and movable floors working together with horizontal augers provided with blades that have to evenly distribute the feed into the feed mixer hopper and simultaneously chop it, if in bales, or crumble it if in blocks. Maize and grass silage are usually introduced loose. Other models provide the possibility to handle products in blocks (Trioliet); in this case an automatic cutting device and a rubber made conveyor are provided. Mixed-concept containers (Agro X, Pellon, Wasserbauer) have the possibility to handle silage blocks: these are loosened up when loaded by the horizontal-auger unloading device. Other systems (Airablo) introduce hay/straw choppers in order to reduce the volume and size of these products and facilitate the mixing process. The

Table 2. Range of technical parameters variability in AFS based on feeder wagon

Parameter	Unit	Range of variability	
		Min.	Max.
Roughage temporary storage	n.	0	4
Temporary storage capacity (if present)	m ³	9	20
Stationary mixer	n.	1	4
Capacity of stationary mixer	m ³	6	50
Power of stationary mixer (each)	kW	4	44
Power for accessories (i.e. discharge door, etc.)	kW	0.75	1.0
Capacity of feeder wagon (FW)	m ³	1.76	4.3
Power of FW moving floor system*	kW	2.7	4.4
Power of FW displacement engine*	kW	0.37	0.5
Power of FW discharge conveyor*	kW	0.7	0.75
System energy requirement (av.)	kWh day ⁻¹	20	35

* Either battery or line powered

ration is freshly prepared by low volume mixer wagons at preset interval (1-15 times per day). The mixer wagons are provided with different mixing systems (vertical or horizontal augers, reels, chain and slats), generally without blades, and are electric powered either by line or batteries. More technical details are shown in Table 3.

Table 3. Range of technical parameters variability in AFS based on mixer wagon

Parameter	Unit	Range of variability	
		Min.	Max.
Roughage temporary storages	n.	1	7
Capacity of temporary storage	m ³	7	50
Power of temporary storage (each)	kW	2.2	3.4
Capacity of mixer wagon (MW)	m ³	1.75	4.4
Power of MW mixing system*	kW	2.2	3.0
Power of MW displacement engine*	kW	0.75	0.8
Power of MW discharge conveyor *	kW	0.55	0.8
Power for accessories (i.e. brushes, etc.)	kW	0.55	0.55
System energy requirements (av.)	kWh day ⁻¹	30	45

* Either battery or line powered

Self propelled feeder mixers This system consists of a fully-automated self propelled mixer wagons such as the Innovado prototype, manufactured by Schuitemaker. The system is similar to conventional self propelled feeder wagons, but with a lower hopper volume (6 m³); a 48 kW diesel engine powers the system that operates completely without operator on board. The wagon is provided with a block unloader that can fill a vertical auger mixing device. An adjustable navigation system allows integration of these robots in existing barns without structural modifications and navigation to predetermined farm storages and feed group of animal at preset times.

Operator interfaces Different operator interfaces are presently available: ranging from ECU (Electronic Control Unit) with display and touch controls embedded on the stationary mixers and mobile wagon to full systems with dedicated PC and/or touch screen, displaying all the information recorded (rations, groups, programmed distributions, etc.). Some manufacturers foresee the use of dedicated office remote controls or portable PDA (Personal Digital Assistant) to adjust and operate the system. ICT standard developments that integrate feeding programs and other farm software can be a valuable further development.

Classification of Automatic Feeding methods Based on the analysis of the currently available AFS's a classification can be proposed as shown in Figure 2.

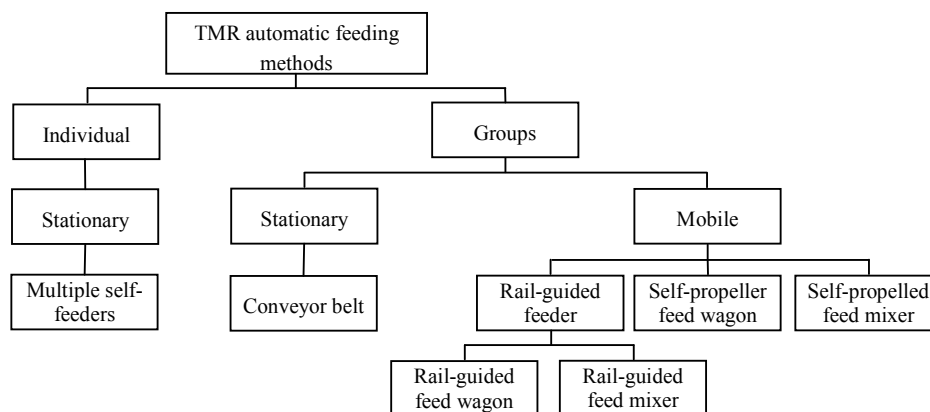


Figure 2. Classification of different AFS for TMR following the design concept.

The currently available AFS's can be described with four process charts (Annex A). Major differences concern the complexity of the mechanized chains with or without the possibility of temporary storages for several days, the intervals between the preparation of TMR and the presence of stationary or mobile chopping/mixing units.

Automatic Feeding strategies One of the main aspects that characterizes the automatic feeding technique concerns the possibility to increase the TMR distribution frequency in order to manage the feed intake, stimulate cow activity, reduce leftovers and to adapt the volume of ration to the size of the animal group. In the case of the conventional mixer-wagon-based feeding technique, the distribution of the ration is generally achieved with a rate of 1-2 cycles per day and per group followed by a variable number of replenishments of the feeding area thus not differing, from a management point of view, from conventional *ad libitum* feeding techniques. With the AFSs the feeding frequency could be increased to 15 cycles per day. Figure 3 provides a schematic overview of the available ration on the feed bunk in the course of a day for a conventional TMR feeding strategy (left) and for a possible strategy with an AFS (right side of figure).

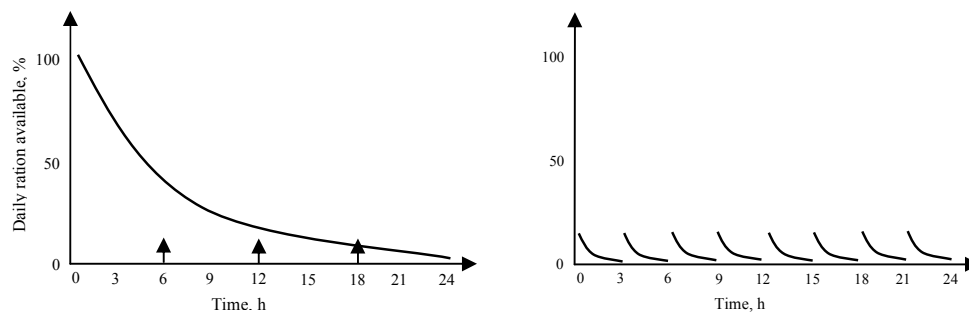


Figure 3. The conventional method to feed TMRs (left) with one distribution per day with three push ups with the leftovers (arrows). The AFS (right) can vary the frequency up to more than 10 distributions per day.

In the case of the conventional feeding system, the ration is provided once a day and it is available for cows in decreasing quantity. The quality will vary as a result of animal selection and intake. A number of push up (3-6 times per day or higher with automated systems) is necessary to keep the feeds within reach of the cows. The example for the AFS displays a strategy where 12.5% of daily ration is distributed with 3 hour intervals. In this case, the reduced quantity distributed could induce cows to reduce feed selection. A second strategy could allow reducing the quantity distributed during the part of the day with less cow activity (Figure 4, left).

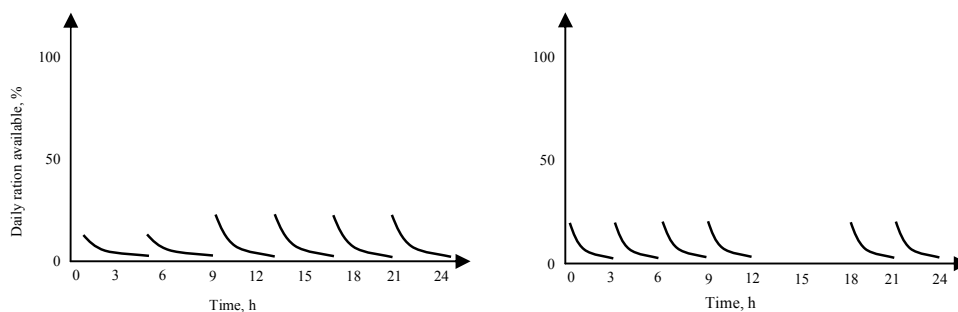


Figure 4. The AFS can be set to reduce the TMR quantity distributed during the night when cows activity is lower (left). The TMR distribution can also be interrupted during the warmest hours (right) when cows rest.

In this case a frequency of 6 distributions per day is set up so that 10% of the daily quantity is distributed twice during the night and 20% is provided 4 times during day.

Another option is to apply a seasonal strategy. The right side graph in Figure 4 show a possible strategy for the summer time where the 6 distributions per day of 16.6% of the daily ration each are supplied during the cooler hours of the day when the cows are more active and the feed is less prone to fermentations.

Variation of the feeding frequency also provides the option to adapt the TMR quantity to be prepared for a wide range of animal group sizes including the small groups (i.e. the transition cows group) as shown in example in Figure 5.

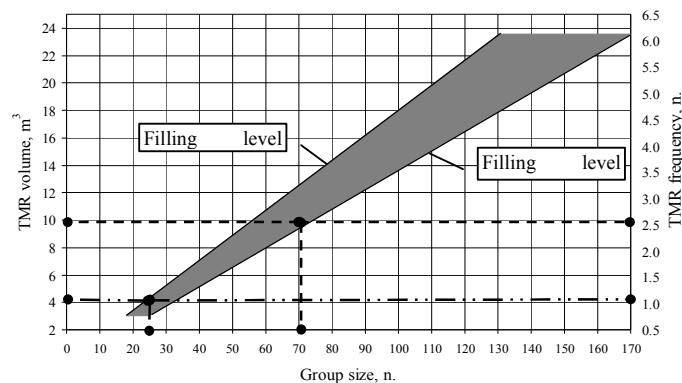


Figure 5. Relation between the required TMR volume and the associated distribution frequency for different herd sizes (----- 70 cows; -·-·-·- 25 cows, see text below for further explanation).

The graph shows the relation between the required TMR volume and the associated distribution frequency for different herd sizes. The grey bar is an example for a feed container of 4 m³, with a filling level between 70 and 90% of its rated capacity (2.8 and 3.6 m³, respectively) and a TMR requirement of 0.125 m³ of feed/cow-day. A herd of 70 cows then requires 8.75 m³ feed/day and a distribution frequency of 2.4 if the filling level is 90% or of 3.1 at a filling level of 70%.

Automatic Feeding management Following the design concepts shown in Annex A before, different management modes – each with their own influence on labour and energy demand – are feasible. The automated distribution reduces the labour demand: labour is only needed to fill the system with single compounds and to manage the rations. Temporary storage allows autonomy of two-three day, but a seasonal adaptation must be taken into account so that the temporary storage must be shortened in warmest seasons.

Most AFS's are electric powered which provides the potential to reduce energy costs if it is combined with the installation of a biogas plant. In addition, the transportation of small feed quantities can be achieved with low powered engines that allow generally low daily energy consumption.

CONCLUSIONS Automatic feeding systems (AFS) for TMR preparation in dairy husbandry are the newest options that can support farmers in their feeding management. Many different systems are presently available or in development. Various feeding strategies show potential benefits, but further investigations are necessary develop design guidelines for a better integration in new or existing barns, to take into account actions for monitoring the mixing consistency among batches, to

reduce the leftover and to dynamically adjust the quantity to be prepared, to better understand the impact on cow behaviour and to integrate information technologies for more accurate dairy management.

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APPENDIX A

TMR preparation and delivery processes with different AFS designs.

