Milking frequency management in pasture-based automatic milking systems: A review

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ABSTRACT

The integration of automatic milking systems (AMS) with pasture-based dairy farming creates a new spectrum of challenges, different to those of indoor-based feeding systems. In order to formulate the correct research questions in areas that are likely to have the highest impact, there is a need to identify gaps within existing knowledge. Therefore, the objective of this review was to bring together, analyse and summarise relevant scientific literature from studies conducted in pasture-based AMS. The focus was placed on describing different animal, feed and management-related factors and their influence on milking interval (MI) and milking frequency (MF). The analysis of 21 studies in the literature in which AMS was combined with variable levels of grazing, indicated a wide data range in variables such as access time to pasture, distance to pasture, cows/milking unit, number of fetchings performed per day, minimum MI setting as well as MI, MF and milk yield achieved. Furthermore, the analysis showed that variability in MI and MF was present both between and within cows and farming systems. In general, pasture-based AMS cows appear to achieve lower MF than indoor-based feeding AMS cows with different access times to grazing, but there were no studies on the actual impact of different MI and MF on milk yield in pasture-based AMS cows. The lower MF of pasture-based AMS cows appeared to be associated with lower levels of cow traffic when AMS was combined with grazing, which highlights the need to test alternative management practices that could potentially increase cow traffic. Changes in frequency and location of feed incentives were identified as areas where further research is required. Overall, this review has identified key aspects of pasture-based AMS that should be taken into account to modify management strategies in these systems, with the aim of optimising MF and system utilisation.

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The first AMS farms were established in Europe in the early 1990s in intensive indoor feeding barn systems and since then over 10,000 farms globally have adopted this technology (de Koning, 2011). A large proportion of installations operate in indoor feeding systems, some of them allowing their cows to graze during certain periods of the year (Ketelaar-de Lauwere et al., 1999b; Sporndly and Wredle, 2004; Sporndly et al., 2004). In these indoor feeding systems cows are housed and fed in barns for all or most of the year, and when in combination with AMS they are referred to as ‘indoor-based AMS’ throughout the manuscript. In 2001, AMS were introduced in grazing farms in Gippsland, Australia on a commercial farm (Greenall et al., 2004) and in Waikato, New Zealand as a research project (Jago et al., 2002, Jago and Woolford, 2002). In contrast to indoor feeding systems, in pasture-based systems cows are not housed in barns, instead they are kept outside and obtain over 50% of their annual requirements from grazed pastures or forages, and when in combination with AMS they are referred to as ‘pasture-based AMS’ throughout the manuscript. In 2006, an AMS research farm was commissioned within the FutureDairy Project in Australia (Davis, 2006; Garcia and Fulkerson, 2005; Garcia et al., 2007), which demonstrated that pasture-based AMS could still maintain high levels of pasture utilisation. Since the concept of successfully incorporating AMS into pasture-based farms has been proven, adoption in Australia and New Zealand has continuously increased (K. Kerrisk, The University of Sydney, Australia and J. Jago, DairyNZ, New Zealand, personal communication). The ongoing interest of pasture-based AMS internationally is evidenced by research programs at Michigan State University in the US (Utsumi, 2011) and the recently announced research programme at Teagasc, Moorepark in Ireland together with the EU project Autograsmilk (O’Brien, 2012).

The establishment of pasture-based AMS creates a new spectrum of challenges, as these systems aim to manage moderate to large herds (>200 milking cows), with considerable distances between paddocks and dairy facility, whilst maintaining production targets.
and 90% of total time. Whilst there are many influencing factors, there are two main considerations that affect milk harvested per AMS unit: the number of cows milked and the MF of those cows (Pettersson et al., 2011). Optimisation of these 2 factors is necessary and will be specific to the farms overall targets. The approach harnessed by the Greenfield project in New Zealand was to milk more cows less frequently; a herd of 110 cows per AMS unit had a target MF of 1.3 milking events/cow per day (Woolford et al., 2004). In line with this, a report by van Dooren et al. (2004b) highlighted the possibility of managing more milking cows per milking unit in a system with unrestricted grazing given the lower MF achieved. On the contrary, milking fewer cows more frequently is the aim of most AMS farmers and the common situation found in indoor-based AMS that also have smaller herds with higher production levels per cow, which influences the scale of the positive relationship between MF and daily milk yield (Garcia and Fullerson, 2005).

This review summarises current knowledge on pasture-based AMS, with specific focus on MF as a key factor that may affect (and could be manipulated) production efficiency and system utilisation. It is neither the intention of this review to address all possible ways of increasing milk production in an AMS nor to suggest that increasing MF should be a sole target on any AMS farm. Other factors (for example animal welfare, milk quality, production costs and impact on labour and lifestyle) should also be considered by any farmer thinking of adopting AMS, but are not the main focus of this review.

2. Milking frequency and milking interval

2.1. Effect of milking frequency on daily milk yield in conventional milking systems

In conventional milking systems (CMS) there is a positive daily milk yield response to increases in MF (Stockdale, 2006). This is partly explained by a more frequent removal of a negative feedback protein (FIL, factor of inhibition of lactation) (Wilde et al., 1995) as well as of other proteins such as serotonin that are responsible for having a negative effect on milk production (Collier et al., 2012). Furthermore, higher MF could have a positive impact on daily milk yield through an increase in secretory cell activity (Capuco et al., 2003). The positive response could also be enhanced by a higher frequency of feeding, which could reduce pH fluctuations and increase feed use efficiency (Garcia and Fulkerson, 2005). By milking cows 3 times per day (around 8 h MI between consecutive milking events), as opposed to the conventional twice-a-day (around 12 h MI between consecutive milking events), an increase of around 15% (Stockdale, 2006), or 3.5 kg milk/cow per day has been reported, regardless of initial production levels (Erdman and Varner, 1995). An additional 20% increase in milk production by milking cows 6 times per day (around 4 h MI between consecutive milkings) in comparison to 3 times per day has also been reported (Stockdale, 2006). Responses of similar magnitude (~20%) have been found by reducing MF from the traditional twice-a-day to once-a-day milking regime (Davis et al., 1999; Stelwagen et al., 2013; Stockdale, 2006). Studies conducted in CMS in New Zealand with cows milked once-a-day (around 24 h MI between consecutive milking events) throughout the whole lactation, reported a greater reduction in milk yield for Holstein-Friesian than Jersey cows (around 69% and 78% milk production than the traditional twice-a-day regime, respectively) (Clark et al., 2006).

Most of the responses to either a decrease or increase in MF are dependent on stage of lactation, parity or duration of treatment. Greater increases in daily milk yield resulting from more frequent milking were observed in early lactation and the response decreased as lactation progressed (Pettersson et al., 2011). The same was true when MF was reduced from 2 to 1 milking events/d, where cows in early lactation had slightly greater proportional losses in daily milk yield than those in late lactation (Davis et al., 1999).

The effects of a higher MF in early lactation could even potentially have an additional carry-over effect beyond that period (Kissell et al., 2007; Wall and McFadden, 2008; Phyn et al., 2010; Soberon et al., 2011) by increasing lactation persistency (Osterman and Bertilsson, 2003). It has also been suggested that a lower MF in early lactation could not be compensated by higher MF thereafter (Svennersten-Sjauinja and Pettersson, 2008). This is particularly interesting in AMS where efforts could be placed on some cows to optimise their MF over a short period of time. Clark et al. (2006) suggested that the drop in milk production by milking once-a-day was greater for primiparous than multiparous cows, and Maltz et al. (2003) reported lower increases in milk yield with higher MF for higher parity cows, which could be related to udder capacity to store different volumes of milk. Davis et al. (1999) highlighted that the drop in milk yield by milking once every 24 h may be dependent on the duration of the reduced MF, something that contradicts the hypothesis of Wall and McFadden (2007) that timing of frequent milking was more important than duration.

2.2. Effect of milking frequency on daily milk yield in automatic milking systems

All the above-mentioned responses in milk production were obtained with consistent intervals between consecutive milkings, given that in CMS usually the MI is around 24 h for once-a-day milking, around 12 h for twice-a-day milking and around 8 h for thrice-a-day milking. In AMS, due to the voluntary and distributed nature of cow traffic, there is usually a variability of MI within and between cows and days (Hogeveen et al., 2001; de Koning, 2011). On any particular day, in AMS two cows may have the same mean MF, but with completely different MI and quite different to a 12:12 h regime. However, Remond et al. (2009) found that daily milk yields corresponding to milkings with intervals of 7:17 h and 5:19 h were not significantly different to a traditional twice-a-day milking regime (11:13 h and 10:14 h respectively), which could indicate that a level of flexibility exists for cows to adapt to a short and long MI. In that study, only cows with a very short and very long MI (3:21 h) had an 11.5% reduced daily milk yield compared to an 11:13 MI regime. Therefore,
### Review of 21 studies in which automatic milking systems (AMS) were combined with grazing.

<table>
<thead>
<tr>
<th>Systems</th>
<th>Focus of the study</th>
<th>Time (h)</th>
<th>Distance (m)</th>
<th>Cows/milking unit</th>
<th>Fetching (n/d)</th>
<th>MMI (h)</th>
<th>MI (h)</th>
<th>MF (events/cow/d)</th>
<th>MY (kg/cow/d)</th>
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<tr>
<td>Indoor-based AMS (&lt; 24 h/d grazing)</td>
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<td>6</td>
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<td>2.6–2.8</td>
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<td></td>
<td>Sward height and distance (2)</td>
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<td>2</td>
<td>6</td>
<td>–</td>
<td>2.8</td>
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<td></td>
<td>Access to a field (3)</td>
<td>8</td>
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<td>16</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>2.5</td>
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<td>Feasibility farm survey (4)</td>
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<td>0–4</td>
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<td>1</td>
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<td></td>
<td>Feasibility study (6)</td>
<td>7</td>
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<td>65</td>
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<td>Feasibility study (6)</td>
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<td>2.6–2.7</td>
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<td></td>
<td>Fetching (n/d)</td>
<td>2.6–3.1</td>
<td>–</td>
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<td>2</td>
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<td>Dominance and behaviour (12)</td>
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<td>2</td>
<td>6</td>
<td>–</td>
<td>1.6–2.1</td>
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<td></td>
<td>Remote selection &amp; water location (13)</td>
<td>24</td>
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<td>41</td>
<td>2</td>
<td>6–12</td>
<td>–</td>
<td>1.42–1.91</td>
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<td>Pre-milking teat preparation (14)</td>
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<td>–</td>
<td>76</td>
<td>2</td>
<td>9</td>
<td>20</td>
<td>1.2</td>
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<td></td>
<td>Milk harvesting efficiency (15)</td>
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<td>2</td>
<td>9</td>
<td>12–20</td>
<td>0.9–1.9</td>
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<td></td>
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<td>17–23.5</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>26.6–5–28</td>
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<td></td>
<td>Supplements and MMI (18)</td>
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<td>200–400</td>
<td>31</td>
<td>2</td>
<td>6–12</td>
<td>13–17</td>
<td>1.4–1.9</td>
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<td></td>
<td>Pre-milking teat preparation (19)</td>
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<td>&lt; 1,000</td>
<td>57</td>
<td>2</td>
<td>5</td>
<td>–</td>
<td>1.6</td>
<td></td>
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<td></td>
<td>Systems comparison (20)</td>
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<td>–</td>
<td>82</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>1.5–1.8</td>
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<tr>
<td></td>
<td>Training systems comparison (21)</td>
<td>24</td>
<td>–</td>
<td>37</td>
<td>2</td>
<td>4</td>
<td>–</td>
<td>1.74–2.65</td>
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</tbody>
</table>


* Access time to pasture.

b Distance to pasture.

c Ratio of amount of cows per milking unit.

d Number of times fetchings were conducted.

e Minimum milking interval.

f Milking interval.

g Milking frequency.

h Daily milk yield.
extreme MI could have a negative effect on milk production. In AMS it is possible that an individual cow milked 2 times within a 24 h period has both MI of 20 h, which results in the opportunity for a short MI to compensate for a long MI being removed. Thus, a proportionally lower daily milk yield would be expected in AMS than CMS, if milking frequency is comparable.

Reports from farms that incorporated AMS stated that MF only increased from 2 milking events/d to an average of 2.5 milking events/d and just a 10% increase in milk yield has been found when transitioning from CMS to AMS (de Koning and Rodenburg, 2004; Svennersten-Sjaunja and Pettersson, 2008). The lack of consistency of MF throughout lactation and the variability of MI that are typical of AMS are possible reasons for the lower than expected increase in milk yield in these systems in comparison with CMS. Achieving regular and consistent MI and MF (low level of daily variation) of cows in AMS is the key to optimising milk production per cow. On the other hand, targeting different MF at individual cow level only seems possible in AMS, where cow traffic can be manipulated through software settings. The ideal MF for each cow should be the result of its production potential, but should also consider factors such as animal welfare (Jacobs and Siegert, 2012) and how motivated the cow is to move voluntarily around the system and respond to incentive allocation (Prescott et al., 1997). Consequently, higher MF should only be targeted on those cows that will respond with a positive increase in daily milk yield (e.g. high producing and early lactating cows). It is possible that cows in pasture-based AMS may not respond to this increase in MF due to the lower levels of milk production and limitations in dry matter intake (DMI). This is different to the condition commonly experienced in indoor-based AMS where high producing cows are usually managed with total mixed rations (TMR) and cows may achieve higher DMI to respond to higher milk production levels typically associated with higher MF.

2.3. Milking frequency in pasture-based automatic milking systems

Grazing can be incorporated effectively into an AMS. A thorough review of the published literature found 21 studies in which AMS was combined with some level of grazing. For the purpose of this comparison, the system types were categorised according to housing and predominate feeding system (indoor or pasture-based AMS). Given that the indoor-based AMS (n=10) were combined with variable levels of grazing, during certain periods of the year (particularly spring and summer), they were further categorised according to daily grazing access time. The ‘Indoor-based AMS (< 24 h/d grazing)’ had grazing access times of 6–15 h/day. The ‘Indoor-based AMS (24 h/d grazing)’ had grazing access times of 24 h/day. The remainder of the studies (n=11) were from ‘Pasture-based AMS’ in which cows were allowed to graze for 24 h/d. Summarised data of the key performance parameters reported in the 21 studies are shown in Table 1, reflecting a range of access time to pasture, distance to pasture, cows/milking unit, number of fetchings performed per day, MMI setting and MI, MF and milk yield achieved. Overall, indoor-based AMS reported in Table 1 tend to have similar distances to pasture, although with variable grazing access, together with fewer cows per AMS unit, more fetchings per day, achieving therefore lower MI and higher MF, in comparison to pasture-based AMS.

Cows perform behaviour or activities in bouts (Ketelaar-de Lauwere et al., 1998; Ketelaar-de Lauwere et al., 2000a) and eat discrete meals (Chilibroste et al., 2007), which has driven research to compare traffic routines in indoor-based AMS. In these systems, incentive and management practices can be put in place (Bach et al., 2009; Ketelaar-de Lauwere et al., 1998) in order to get more regular cow traffic through automatic drafting gates. In turn this enables more targeted selection of when to milk a particular cow. In ‘free traffic systems’ cows have unrestricted access from feeding to lying areas and the main motivation to attract cows to the milking unit is the provision of concentrate. Free cow traffic often results in increased fetching (Bach et al., 2009) but possibly better cow welfare, in comparison to other traffic systems (either ‘controlled traffic systems’ or ‘forced traffic systems’), given that lying and standing times are not compromised (Winter and Hillerton, 1995, Ketelaar-de Lauwere et al., 1998). Free cow traffic systems achieve higher and regular feeding frequency, yet MF is usually low (Melin et al., 2006). In systems without ‘free cow traffic’, the feeding and lying areas are commonly separated, and cows must visit an automatic drafting gate or the milking unit when transitioning between areas. There are two different levels of these systems according to where the selection for milking takes place. In ‘controlled traffic systems’, sometimes also called ‘semi-forced traffic’, cows are required to present themselves at automatic drafting gates when trafficking between feeding and lying areas. At these gates each cow is identified and routed towards the milking unit(s), prior access to a pre-milking waiting area, only if the cow has milking permission. On the other hand, in ‘forced traffic systems’, cows are required to visit the milking unit when trafficking either from lying to feeding areas, or vice versa, where milking also occurs based on milking permission criteria, and there is no pre-milking waiting area. In comparison to free traffic systems, a higher MF (and lower MI) has been reported for cows managed under controlled or forced traffic system. However, they also report a higher proportion of non-milking visits, which in the case of forced traffic use effective available robot time (Bach et al., 2009; Devir et al., 1996; Ketelaar-de Lauwere et al., 2000a). Longer than desired pre-milking waiting area times, in which cows remain standing for extended periods of time which can negatively affect cow welfare, can be observed under controlled traffic managements, which could particularly affect less dominant cows (Ketelaar-de Lauwere et al., 1998; Lexer et al., 2009).

Traffic routines in pasture-based AMS cannot always take advantage of the nature of cows to perform activities or behaviours in bouts, given that cows often perform their 3 major activities (eating, resting and ruminating) in the same location; at pasture. Therefore, different managements, probably more focused on incentives, need to be designed in order to manipulate cow visits to the milking unit and therefore milk production in pasture-based AMS.
2.4. Milking intervals in automatic milking systems

As MI is the inverse of MF, longer MI is logically associated with lower MF and vice versa. The occurrence of very short MI (< 6 h) can have negative effects on udder health due to extended machine cups-on time (Ipema and Benders, 1992). Additionally, these milkings impinge on robot utilisation given the fixed handling time involved in identifying, cleaning and attaching at quarter level and post spraying. From the milking robot point of view, the inefficiency aspect of short MI is less of an issue for those systems operating at low-moderate utilisation levels, where sufficient robot aspect idle time exists. Setting higher MMI could reduce the incidence of these short MI but also lead to an increase in undesirably long MI (> 16–18 h), which have negative effects on milk yield (Schmidt, 1960) and udder health (Hammer et al., 2012). This is partly explained by a non-linear relationship between MI and milk yield. Beyond a certain MI, yield per milking is proportionally reduced (average hourly milk accumulation rate in the udder decreases) and the scale of the impact is likely to be related to initial milk yield and stage of lactation. The MI at which the relationship between MI and milk yield plateaus has been reported to range from 12 h (Knight et al., 1994) to 18 h (Stelwagen et al., 2008), although no information exists for the modern cow, particularly in pasture-based AMS. Stelwagen et al. (2008) reported that a period of frequent milking could not always revert the negative impact of a long MI, whilst Ipema et al. (1997) indicated that with recurrent long MI, milk yield would decrease. Therefore, in most cases the aim would be to reduce the occurrence of these long MI. Hogeveen et al. (2001) reported an average MI of 9.2 h for a 66 cow herd managed in an indoor-based AMS, which equated to a MF of 2.6 milking events/cow per day. However, it was noted that 9.7% of milkings had MI below 6 h and 4.2% MI extended beyond 16 h. Given the variation of MI in AMS, focus should be placed on managing MI (particularly extremes), rather than simply increasing MF (Lauris et al., 2010; Ouweltjes, 1998).

Farmers would benefit from shifting the focus from average MI, to also include concentrating efforts in finding ways of reducing the range of MI occurring (very low and very high MI). In a study by Bach and Busto (2005) an increased weekly coefficient of variation of MI had a negative impact on milk yield. Also, in a comparison of 100 farms from The Netherlands, Mollenhorst et al. (2011) reported that a high variability in MI was related to high somatic cell count (SCC) levels.

Most AMS studies have focused on MF and have not reported data on the range of MI. A high occurrence of long MI has been reported in pasture-based AMS with up to 10% of milkings having MI exceeding 24 h (Davis et al., 2007). There has been no report on the effect of different MF in cows managed in a pasture-based AMS to determine the value of increasing MF. Additionally, there has been no quantification of the association of different factors specific to pasture-based systems (e.g. proportion of pasture in the diet, pasture allowance, distance from the dairy facility to pasture allocation and pre-grazing pasture biomass) on MI and how they could affect milk yield. Findings in these areas should contribute significantly to the development of management guidelines for pasture based AMS and would allow farmers to better manage incentive allocation in order to have the greatest impact on cow traffic.

3. Management of milking intervals and milking frequency in pasture-based automatic milking systems

Farmers willing to incorporate AMS into a pasture-based farming system should consider different animal, feed and management-related factors in order to reduce variability of MI and manage MF in order to optimise production and utilisation targets. First, the main animal-related factors that affect MI and MF will be described. The major focus in this section will then be on those factors associated with incentives that can be manipulated in pasture-based AMS. Last, system-factors will be covered. Overall, they all interact with each other on final MI and MF achieved on farm and therefore their effects should not be considered in isolation. In addition, farmers should ensure that any management put in place does not have negative effects on cow health and welfare aspects.

3.1. Stage of lactation

In a study conducted in an indoor-based AMS that evaluated the individual cow effect on MF of Red Dane, Holstein and Jersey breed cows (Lovendahl and Chagunda, 2011), MF increased in all breeds from calving (2.5–3.1 milking events/d) up to 105 DIM (3.0–3.3 milking events/d) and decreased thereafter (2.7–3.1 milking events/d). In a study conducted in a pasture-based AMS in New Zealand with a herd of 94 cows milked through a single box milking unit, in which cows’ diet comprised pasture supplemented with 1 kg concentrate/milking event, early lactation and high yielding cows were more motivated to visit the milking station than cows in late lactation or of lower milk yield (Jago et al., 2006b). In comparison to late lactation cows, the early lactation cows had lower average MI (14.6 versus 20.4 h respectively) and higher MF (1.7 versus 1.2 milking events/d respectively). Furthermore late lactation cows were more likely to be those that required fetching from the pasture allocation (8% of early and 23% of late lactation cows required fetching), which is in agreement with the data reported by Ipema and Benders (1992). The decrease in milk yield as lactation progresses could explain the reduction in the effectiveness of the feeding incentive resulting in the reduced response displayed by the late lactation cows. Early lactation cows are expected to have stronger appetites, in order to satisfy their higher milk production requirements, and therefore achieve higher levels of voluntary cow traffic and as a consequence would gain access to fresh feed more regularly than late lactation cows. By doing this, early lactation cows would satisfy their intake requirements from the abundance of good quality pasture. These cows would also be the first ones to voluntarily leave allocated paddocks avoiding grazing horizons of pasture of potentially lower quality. It is also possible that the higher levels of concentrate allocation of early lactation cows could also create the higher level of voluntary cow traffic. Nixon et al. (2009)
stated that farmers should focus on early lactation cows that do not achieve a high MF (especially lower than 1 milking events/d) given that normally they should be highly motivated. According to Jacobs et al. (2012) stage of lactation also affected cow traffic through the dairy facility in an indoor-based AMS, with early lactation cows moving faster through the exit alley of the milking unit, in comparison to mid or late lactation cows. Although cows in early lactation have a higher response in daily milk yield to variations in MF, it is important to understand how cows in different stages of lactation can be motivated in order to design protocols to influence MF throughout lactation, as it is likely that they may respond in different ways to different incentive managements.

3.2. Parity

Younger cows are more inclined to traffic around the system voluntarily achieving higher MF (Sporndly and Wredle, 2004; Borderas et al., 2008), although they usually have higher waiting times in front of the milking unit than their mature herd mates (Donohue et al., 2010). The difference in size or social ranking could explain why older cows, which gain quicker access to the milking unit, dominate younger cows. In contrast, during training, heifers were inclined to be quicker learners with regard to trafficking through the gates voluntarily but required more time to adapt to the actual milking procedure, whereas older cows struggled with the traffic around the system, but were more confident once they were in the milking crate (Jago and Kerrisk, 2011). In the study by Lovendahl and Chagunda (2011) that reported MF of Red Dane, Holstein and Jersey breed cows, primiparous cows were more persistent than multiparous cows throughout lactation. Likewise, Pettersson et al. (2011) reported that the drop in MF throughout lactation was higher for cows than heifers (−0.21 and −0.06 milking events/d from DIM 165 to 235 respectively).

3.3. Cow dominance

Only the study by Jago et al. (2003) evaluated the combination of AMS with grazing focused on the association of cow dominance on behaviour (Table 1). Dominant cows (determined by the proportion of cows within the herd that were subordinate to each cow) trafficked frequently across the system, achieving 18% higher MF but had no difference in daily milk yield. They even waited for shorter periods of time and gained priority access to the milking unit compared to less dominant animals. It is likely that lower ranked cows might choose to visit the milking unit at less popular times, to avoid contact and minimise exposure to sharing areas with more dominant cows of which they may fear (Ketelaar-de Lauwere et al., 1996). Additionally, a higher number of cows/milking unit may also affect performance of less dominant cows by reducing their MF (Rotz et al., 2003).

3.4. Training and previous experience

Adequate training of naive heifers and cows into the whole AMS is required to ensure higher levels of voluntary cow traffic and minimal losses in milk production. Training heifers by exposing them to the milking unit pre-calving has proven to be effective to achieve adequate MF post-calving (Donohue et al., 2010). In a study conducted in a pasture-based AMS in New Zealand, cows subjected to no training had longer entry times into the milking crate than a group exposed previously to some level of training, but there was no difference in time to achieve the first voluntary milking (Jago and Kerrisk, 2011). Work conducted at the first AMS research farm in Australia, indicated that it is much easier to train early lactation cows that are more motivated and feed-driven than late lactation cows. However, training appeared to have a higher negative impact on immediate and subsequent milk production of the early lactation cows (Davis et al., 2007). Therefore, some authors have suggested that it would be better to train late lactation cows or even dry cows, to minimise production losses, although some extra labour, time and effort could be involved.

3.5. Climatic conditions

Reports from early adopters in New Zealand (Jago, 2009) and studies conducted in Europe (Ketelaar-de Lauwere et al., 1999b) indicated that weather can have a strong impact on cow traffic when animals are on pasture. They identified that rainy and windy conditions slow down voluntary movement, whereas traffic is increased with hot temperature or very heavy rainfall as cows traffic to the dairy facility in search of shade or shelter. Additionally, Halachmi (2004) highlighted the importance of considering a whole system approach within a simulation model to design an AMS in a hot climate, where cooling locations should be effectively integrated within the system.

3.6. Water

Jago et al. (2005) conducted a short term study with late lactation cows in a CMS in New Zealand to investigate the use of water as an incentive to stimulate cow traffic. The authors found that cows fed TMR were more likely to consume water evenly throughout the day than cows on pasture. Drinking behaviour of grazing cows was more concentrated in day-time and was strongly related to milking session times. Despite that, water was effective in motivating individual cows (as opposed to group movement), which suggests that it could be combined with other incentives to increase cow traffic. Sporndly and Wredle (2005), working with cows in mid lactation, tested the location of water troughs either in the barn or in the barn and pasture, with cows grazing at distances between 50 and 330 m. Negligible differences in amount of water consumed, MF or milk yield were found. The provision of water only in the barn was not a strong incentive for cows to return from pasture, but did cause an increase in the proportion of daily water intake that took place in the barn during the first 30 min after entering. Interestingly, Jago et al. (2003) found that when drinking water was available in the pasture allocation, 83% of all drinking events occurred in the allocation. It has been reported that dairy cows obtain their daily water requirements from a balance
between drinking water and water in feed (Estrada et al., 2004), so depending on weather (temperature and humidity, related to season), milk production, forage type and quality, water might not act as an incentive at all. In Australia where temperatures reach over 30 °C in summer, the use of water as an incentive to generate cow traffic may act as a ‘restriction’ and compromise animal welfare by predisposing heat stress conditions, which will in turn negatively affect milk production.

3.7. Pasture allocation

In a pasture-based AMS cows are not forced to remain in a pasture allocation, they may voluntarily walk out in search for more or better quality feed (amongst other things for example shade or shelter). Pasture biomass is likely to be the main influence on cow behaviour in a pasture-based AMS and it is expected it will have a strong influence on when cows decide to walk out of a given allocation. Ketelaar-de Lauwere et al. (2000b) reported an increase in cow traffic from pasture to the dairy at lower pasture heights or biomass, which in turn resulted in greater MF. Likewise, Chilibroste et al. (2012) found that cows had a higher probability to be grazing and at a higher bite rate, at the start of the grazing session, regardless of initial allowance. Sward height can also influence bite mass, which affects total DMI (Barrett et al., 2001; Rook et al., 1994). The arrival at pasture could act as a strong incentive for cows to graze actively, although the effectiveness of the incentive could fade in time. Under CMS management cows graze actively as soon as they enter an allocation and respond to an increase in available grazing time by increasing time spent grazing, although this increase is not proportional (Chilibroste et al., 1997; Perez-Ramirez et al., 2009). Similarly, cows may modify grazing behaviour to compensate for different time available in the allocation in order to achieve similar daily DMI (Gregorini et al., 2009; Kennedy et al., 2009). In pasture-based AMS animals arriving at an allocation at different times may express different behaviour patterns that could explain the occurrence of different MI. Furthermore, given that in pasture-based AMS not all cows arrive to the pasture allocation at the same time, it is therefore expected that cows will have reduced synchronisation and competition. If available grazing time is substantially reduced, DMI and therefore milk yield will likely be compromised (Perez-Ramirez et al., 2009). Yet to date no studies of cows in pasture-based AMS have analysed how animals modify their grazing behaviour according to time spent on pasture or MF. Understanding this is critical to make sure cow time budgets and animal welfare is not compromised.

The analysis of data from those studies presented in Table 1 show a wide range in access time to pasture. An increase in the time cows were offered access to pasture was associated with a decrease in MF (Fig. 1). Cows managed in indoor-based AMS and allowed to graze for less than 24 h/d had a (mean ± SE) MF of 2.64 ± 0.06 milking events/cow per day (range 2.40–2.85 milking events/cow per day). Cows in indoor-based AMS that were allowed to graze for 24 h/d had a (mean ± SE) MF of 2.40 ± 0.06 milking events/cow per day (range 2.20–2.70 milking events/cow per day). On the other extreme, cows that were managed in a pasture-based AMS had a (mean ± SE) MF of 1.61 ± 0.12 milking events/cow per day (range 1.10–2.30 milking events/cow per day). This was much lower and much more variable than the results reported for indoor-based AMS with variable times on pasture (Fig. 1). The highest MF reported for pasture-based AMS (2.1–2.3 milking events/cow per day) were very similar to the lower range limit of indoor-based AMS with grazing (2.2–2.3 milking events/cow per day).

Cows in indoor-based AMS with some level of grazing had similar MF to the one reported in studies conducted in indoor-based AMS with no grazing access, at around 2.5 milking events/cow per day (Nixon et al., 2009; Pettersson et al., 2011). Time spent eating is one of the main reasons that could explain the differences in MF between pasture-based and indoor-based AMS. Grazing cows spend almost double the amount of time eating that those in TMR systems (Bargo et al., 2002). Furthermore, grazing cows tend to display a higher synchronisation in behaviour (Thorne et al., 2003), especially of activities such as grazing (Ketelaar-de Lauwere et al., 1999b; Rook and Huckle, 1995). Additionally it is not unusual that cows, when given the choice, prefer to spend considerable amount of time indoors, and not on pasture (Charlton et al., 2011). Other possible reasons for a higher MF observed in indoor-based AMS are higher frequency of fetching or restrictions on which cows are allowed outdoors.

Grazing systems may influence cow traffic and visits to the dairy facility (van Dooren et al., 2004b). In indoor-based AMS that offer access to pasture, usually only one allocation of pasture is given to the herd per day, because most of the cows’ diet is provided in the barn (mixed ration and concentrates). In pasture-based AMS daily pasture allocation has traditionally been managed by giving the herd access to 2 allocations in any 24 h period. Each of the allocations has approximately half of the daily pasture allowance and the interval between allocation availability is 12 h. These have traditionally been referred to as ‘day’ and ‘night’ pasture allocations. Every time cows traffic from one allocation to the other, they must present at automatic drafting gates where milking permission is
granted and cows are drafted to the dairy, or milking permission is denied and cows are drafted to pasture. This management has resulted in high levels of pasture utilisation in pasture-based AMS (Davis et al., 2006), but relatively low MF. It is reasonable to believe that an increase in the frequency of pasture allocations (3 pasture allocations in any 24 h period, instead of the traditional 2 allocations for example), each one of them being smaller in size, whilst still maintaining same daily allocation, should encourage cow traffic in the system and therefore increase MF and milk production. However, not all farm layouts lend themselves to provision of more than 2 daily pasture allocations and it is important that pasture-based farmers can make informed decisions regarding the need to modify their farm layout prior to adoption of AMS. Therefore, a quantification of the impact of providing more than 2 pasture allocations per day would need to be conducted.

Previous studies conducted in pasture-based AMS reported that increasing feeding frequency did not affect milk yield, total grazing time or DMI (Dalley et al., 2001; Granzin, 2003). However, the authors reported a shift in grazing pattern during the day. This could imply that feeding frequency may not necessarily impact on a higher DMI, but that it could instead affect intake pattern, which in an AMS has the potential to relate directly to cow traffic and indirectly to MF. Cows housed in an indoor barn had a more even distribution of feeding activity, as well as an increase in nocturnal feeding associated with more frequent meals (DeVries et al., 2005). In a commercial pasture-based AMS farm in New Zealand, a setting of 4 breaks of pasture per day during certain times of the year (when cow numbers were at maximum) resulted in higher MF and a more evenly distribution of milking events throughout the 24 h period (Jago, 2009).

Orr et al. (2001) reported an increase in duration of the evening meal when daily forage allowance was allocated following the afternoon milking, although cows usually concentrate the majority of grazing events during the day time and in early morning and early evening (Gibb et al., 1998; Gregorini, 2012). Interestingly, Sheahan et al. (2013) found that cows supplemented in the afternoon spent more time ruminating during the hours of darkness than cows that were supplemented in the morning. This could imply that allocation of incentives at different times during the day has an effect on cow behaviour which may impact on cow traffic, especially at times when cow movement is typically reduced. In pasture-based AMS, if pasture allocated during the day were to be depleted in early hours of the night and another feed source became available at that time, it is possible that cow traffic could be encouraged and a higher number of milkings could be observed during the night period and particularly during the early hours of the morning (0200–0600 h). Although this hypothesis has not been tested, it is important that any management put in place does not negatively compromise cow time budgets and animal welfare. Observations conducted in a pasture-based AMS have shown that cows that arrive at the dairy facility during night time, as opposed to those that arrive during the daytime, have a greater probability of spending more time in the pre-milking waiting area on average (V. E. Scott, The University of Sydney, personal communication).

In pasture-based AMS, allocation of area to be grazed is based on the assumption that the whole herd will gain access to each allocation. Therefore, if for any reason voluntary cow traffic were affected, a temporal over-allocation of pasture could occur. This is expected to reduce cow traffic back to the dairy facility due to an effective over-allocation of incentive in one area. If the possibility existed to allocate the area according to number of cows actually present, it would be likely that shorter average MI could be achieved. This would require an accurate prediction of how many cows would be drafted to pasture during a particular time period. Current AMS software does not generate daily or historical reports on the proportion of the herd that gain access to each pasture allocation. If this were known, an adequate pasture area could be set accordingly, which would involve moving of temporary electric tapes either manually or automatically. However, care would have to be taken to ensure that over feeding or under feeding did not occur across the herd.

Most indoor-based AMS that incorporated access to pasture had cows grazing at a relatively short distance from the dairy (<500 m). The literature reports shorter MI when grazing up to 50 m from the dairy (Spornldy and Wredle, 2004), but no effect of distance between 150 and 360 m on visits to the dairy and MF (Ketelaar-de Lauwere et al., 2000b), or up to 500 m on MI and amount of cows fetched (van Dooren et al., 2004c). In most of those studies, a high proportion of the daily feed allocation was provided as TMR indoors and a strong fetching routine was implemented.

In contrast, pasture-based AMS such as those common to Australia and New Zealand are likely to have cows grazing at distances up to 1–1.5 km away from the dairy facility. The impact of distance from the dairy facility to the grazing area, in pasture-based AMS with a high proportion of grazed pasture in the diet is unknown. Given the ongoing trend of increasing herd size, distances of further paddocks to milking units are expected to increase. Long walking distances may impose a baseline limitation to MF. The incorporation of forage crops as a way to increase the proportion of home-grown feed (Farina et al., 2011) has the advantage and potential to grow more feed in close proximity to the dairy facility, which would minimise walking distance and has the potential to re-define the whole feeding management within pasture-based AMS.

3.8. Supplementary feed

In pasture-based AMS the use of supplementary feed can be a tactical decision to either cover pasture feed gaps, control or increase DMI, achieve high production levels or encourage cow traffic from pasture to the dairy (Salomonsson and Spornldy, 2000).

The provision of concentrate at the milking unit has the potential benefit of encouraging cows off pasture and into the milking unit itself, both of which could reduce MI. However, the provision of 1 kg crushed barley/cow per day in the milking unit caused no difference in MI (14.46 h) or MF (1.66 milkings/cow per day) of cows in a pasture-based AMS (Jago et al., 2007). It is possible that the
provision of such a small amount of incentive combined with the longer walking distances associated with the farm layout were insufficient to significantly motivate the cows. Prescott et al. (1998) reported that only high yielding cows increased visits to the milking unit when feed was offered after milking, as opposed to when no feed was offered after milking. Bach et al. (2007) compared daily concentrate levels of 3 and 8 kg/cow per day made available in the milking unit in an indoor-based AMS and found no difference on overall MF (2.7 milking event/cow per day) or on the proportion of cows that required fetching (27% of cows). A lack of response to concentrate levels was also reported by Halachmi et al. (2005) when cows in a cowshed in Israel showed no difference in voluntary MF (average 3.1 milking events/cow per day) when either 1.2 kg concentrate/milking or 7 kg concentrate/cow per day were offered. However, Ketelaar-de Lauwere et al. (1999a) found a 15% increase in MF when access to concentrate feeders was only granted after milking, as opposed to being continuously available. It is not known if higher amounts of concentrate on offer than those reported in those previous studies can motivate cows in a pasture-based AMS, where energy intake is a limiting factor. It is possible that an increase in visits to the dairy facility could be induced by offering access to concentrates prior to milking. Yet, this hypothesis has not been tested.

Careful planning and attention to every element within the AMS will favour controlled visits to the milking unit (Ipema, 1997). Given that feed is the main incentive used to manipulate cow traffic and that the effort involved in getting a certain reward could affect the willingness to search for it (Prescott et al., 1998), it is likely that offering feed prior to milking would result in a higher incentive for cows to traffic back to the dairy at shorter intervals due to the immediate reward. Additionally, cows fed prior to milking would have an increased time off-feed, which would enhance feeding motivation once they arrived to the pasture allocation (Chilibroste et al., 1997, 2007).

3.9. Cow time budget, behaviour and traffic

There has been no reported study that quantifies how cows in a pasture-based AMS allocate their time between milking events with regard to time spent in different farm areas (i.e., on pasture, on feedpad, on stand-off, on lanes to and from the dairy, in the pre-milking waiting yard, in the milking crate or in separation pens). If this were known, management could target minimising the time spent in non-productive areas such as the pre-milking waiting yard, which in some cases can also have negative effects on cow behaviour and welfare (Gomez and Cook, 2010).

In a study comparing behaviour of 2 strains of Holstein-Friesian genetics fed either pasture or TMR, the grazing cows consumed around 25% lessDMI (around 5 kg/d less), but spent almost 85% more time eating per day (around 4 h extra) (Thorne et al., 2003). This is in agreement with findings by Bargo et al. (2002) in which cows that had access to a partial mixed ration, in addition to pasture, spent less than half the amount of time grazing than cows that had full access to pasture and concentrate (4.2 versus 9.5 h/d respectively). Grazing is a very time consuming activity for dairy cows and dairy cows perform their activities in bouts, in which periods of grazing are separated by periods of ruminating and idling (Gibb et al., 1997). Therefore time on pasture is most likely to explain a great proportion of MI. Furthermore, in pasture-based systems 90% of grazing occurs in daylight times, particularly in early morning and late afternoon (dawn and dusk) (Gregorini, 2012). This could explain the low frequency of visits to the dairy and therefore few milkings that occur between midnight and 0500–0600 h in pasture-based AMS (Davis et al., 2005; Jago et al., 2002; Woolford et al., 2004).

Given that cows respond to different managements, new technologies have been tested to modify behaviour of individual cows within a herd. For instance, a cow-calling system was tested in Europe (Wredle et al., 2004), in which an audible signal was emitted from a device in the cows’ collar, as a way of indicating cows with long MI to walk back towards the dairy. Cows seemed to respond positively to the sound, yet did not always enter the milking unit promptly. A queue of cows waiting to be milked, together with the low level of concentrate offered (0.7 kg) could have reduced the potential impact of the positive stimuli. Queuing could be a result of cow behaviour in the pre-milking waiting yard, higher cows/milking unit, high number of cows waiting for a limited resource (Jacobs et al., 2012); an uneven cow flow through the system that may result in periods of very high and very low demand for machine occupancy (Halachmi, 2009; Prescott et al., 1997; van Dooren et al., 2004a) a limiting capacity of the milking system (Rotz et al., 2003) or a very high average MF and system utilisation (Ketelaar-de Lauwere et al., 2000a).

3.10. Minimum milking interval

In pasture-based AMS, MMI below 4 h (which would limit maximum MF to 6 milking events/cow per day) have not previously been reported. Most MMI were around 6–10 h (creating a maximum MF threshold of 2.5–4 milking events/cow per day) and were similar to those of indoor-based AMS (Table 1). In a pasture-based AMS in New Zealand a lower MF was achieved for cows with a 12 h MMI, compared with cows that had a 6 h MMI (1.41 and 1.52 milking events/cow per day respectively) (Jago et al., 2007). There was a trend for cows with the higher MMI to visit the selection unit that was at a distance of 200 m from the dairy facility more frequently, but they were refused more frequent access to the dairy. There was no treatment effect on daily milk yield (average 23 kg milk/cow per day).

A study by Andre et al. (2010) in a indoor-based AMS and with free cow traffic access to TMR, reported a possible increase in MF and daily milk yield if MI could be optimised for individual cows by taking MI, milk yield and milking duration, together with occupation rate into account. In that study the actual and optimal MI were around 40% higher (average 9.5–10 h) than the average MMI setting of 7 h (range 5.25–9 h). Therefore, the actual
achieved MF was lower than the target desired MF. In agreement with this, a further study by Laurs et al. (2010) reported that cows housed in an indoor-based AMS managed with a forced cow traffic system, had an actual achieved MF that was between 7% and 31% lower than target desired MF, although in their study only 50% of the milking events had a MI that was within 2 h of target MI.

It would be expected that the difference between target and actual MF would be larger and highly variable among individual cows in pasture-based AMS. Furthermore, in pasture-based AMS, a refusal of milking permission at the automatic drafting gates due to MMI setting could have a negative effect on subsequent MI. It is likely that a high proportion of cows that end up having long MI were refused previously. If this were the case, the best management could probably be to sort them to a pre-feeding area or pasture allocation with lower pasture biomass and closer proximity to the dairy. However, no research has quantified these relationships in pasture-based AMS yet.

### 3.11. Fetching of cows

To avoid long MI, which will in turn reduce MF, a ‘fetching’ routine is generally implemented, especially by cows that have not visited the milking unit or returned to the dairy facility voluntarily are manually herded to the dairy facility. Although this can be a time consuming task (particularly if individual cows are targeted, as in indoor-based AMS), it is a common on-farm practice required to obtain a minimum MF. In pasture-based AMS, usually a large proportion of the cows that require fetching include late lactation cows, cows on heat, lame cows (Borderas et al., 2008), mastitis cows and inexperienced or less motivated cows (Kerrisk, 2009). Fetching increases throughout lactation, is lower in heifers and can be minimised with good management (Pettersson et al., 2011). It is important to understand which cows should be the focus of attention for fetching. Maybe more time and effort should be placed to fetch cows that are in the earlier stages of lactation or higher production levels, which are more likely to respond to variations in MF. For example a cow that is overdue for milking and is 50 DIM is probably a higher priority for fetching than a cow that is 280 DIM. Between 0 and 4 fetchings were conducted per day in studies that combined AMS with grazing (Table 1).

In indoor-based AMS combined with pasture, the number of times fetching was conducted was positively related to the number of hours per day that grazing was allowed (van Dooren et al., 2002) and was a prerequisite if high MF targets were to be realised (van Dooren et al., 2004b).

In indoor-based AMS it is a common routine to fetch between 2 and 5 times per day, with the focus placed on any cow that has not presented for milking in the last 12–14 h. This is possible given that on average these herds have less than 100 milking cows in close proximity to the milking unit. From a survey conducted in Spain that included 29 indoor-based AMS farms, time spent fetching cows was almost 1 h/AMS per day (Castro et al., 2012). This strategy significantly reduces MI and therefore enables the achievement of higher MF. In pasture-based AMS, fetching individual cows that have not been milked within a certain period of time does not seem possible under current management practices. Herds of moderate to large size (defined here as > 200 milking cows), grazing at considerable distances from the dairy facility (around 800–1000 m in many cases) limit this from occurring, at least in a time effective manner. Hence, in pasture-based AMS, fetching does not occur based on cows individual MI but on active access time to pasture allocation. Usually, all the cows that have not voluntarily walked out of the pasture allocation are fetched 2–3 h before opening of a subsequent allocation. Under this management the aim is to allow sufficient time for those fetched cows to be milked and ensure they gain access to every allocation. Reports from the first pasture-based AMS research farm in New Zealand state a lower fetching number in the evening (around 2.5% of the cows) in comparison to the morning (around 10% of the cows) (Jago et al., 2002).

If higher MF was targeted and high levels of voluntary cow traffic were not achieved, fetching would have to increase (either fetch earlier and therefore fetch more cows, or fetch smaller groups of cows but more frequently). There has been no quantification of the proportion of cows that would require fetching in a pasture-based AMS if similar management protocols as in indoor-based AMS could be put in place. In the future, if this were known, the incorporation of technologies such as remote monitoring or global positioning systems (GPS’s) devices attached to animals could start playing a role in helping to identify and reduce MI.

After fetching it is not uncommon to observe a higher than normal number of cows waiting to be milked as well as a higher than average number of milkings to occur soon after, which may increase utilisation of the milking unit (Andre et al., 2010).

Only adequate incentive and traffic management will allow achievement of a high level of voluntary milkings, with minimal fetching.

### 3.12. Incomplete milkings

Mammary gland quarters that are flagged as incomplete due to missed attachments or premature milk cup removal have a subsequent long MI, which negatively affects milk secretion rate. In a study by Bach and Busto (2005) a milking failure extended MI of that quarter by almost 10 h (from 12 to 21.75 h), which translated to a 26% yield loss in comparison to non-affected quarters, regardless of MI. The negative impact of a milking failure was more pronounced towards the end of the lactation. This would probably be related to the even lower number of visits to the dairy facility of late lactation cows in comparison to early lactation cows, which would cause an even higher subsequent MI. In pasture-based AMS the negative impact of incomplete milkings on milk yield is expected to be even higher given that cows have lower frequency of visits and higher MI.

### 3.13. Machine availability

Only when system utilisation levels are low and there is spare milking robot time available, then the farmer can
aim at increasing the number of milkings performed per day (Hogeveen et al., 2001; Rottz et al., 2003). In a pasture-based AMS cow visits to the dairy facility are typically low during the early hours of the day (Davis et al., 2005; Jago et al., 2002; Woolford et al., 2004), causing low utilisation levels (around 60%), which indicates that additional milkings could be performed (Davis et al., 2005). In a report from van Dooren et al. (2004b), an indoor-based AMS that allowed 24 h grazing with 2 daily fetchings, operated 18.2 h per day and had the potential to reach full utilisation (milking 22 h per day) by adding 14 additional cows to the herd and harvesting an additional 336 kg milk/d. Similar numbers of cows on average could be incorporated to AMS farms surveyed in Spain (Castro et al., 2012), which were on average operating at 72% capacity. If there is spare capacity and the farmer considers the possibility of adding extra cows, the impact over the entire system management should be considered in order not to compromise cow welfare (such as eating space, feed allocation, and area dimensions).

The total time spent in the milking unit crate, is related to the speed of robot performance (predominantly cleaning and attachment procedures) and milking speed, which in turn relates to milk production amongst other factors. Studies conducted in pasture-based AMS in New Zealand and Australia reported that by using some type of teat cleaning device (brushes or cleaning cup respectively), milking time was reduced (effective milking time, first cup on–last cup off), but total time in crate (cow in – cow out) was extended (Jago et al., 2006a, Davis et al., 2008). Davis et al. (2008) even quantified that the time cost for pre-milking teat preparation could be used to perform an extra 18% milkings, by either milking more cows or the same number of cows more frequently.

The introduction of the latest development in AMS is a high-throughput robotic rotary (Automatic Milking Rotary, DeLaval, Tumba, Sweden; Kolbach et al., 2012, 2013) that could potentially have a higher throughput capacity (particularly if it is not fully utilised) (around 50 cows/h; Kolbach et al., 2013), compared with single box units that can perform between 6 and 8 milkings/h (de Koning and Ouweltjes, 2000).

If the possibility of incorporating additional animals to the herd is not an option, the aim could be to increase MF by reducing MI of those cows in which a significant proportional increase in milk yield could be obtained. If there is no spare capacity in the system to perform additional milkings, due to a limitation in time, the only possibility to increase MF is to reduce the proportion of milkings with either very short or very long MI, together with managing which cows should be milked at different frequencies.

4. Conclusions and research possibilities

The intention of this review was to analyse and discuss key factors affecting MF and MI, particularly in pasture-based AMS, identifying those areas and questions that still remain to be answered. Key factors that have the potential to be manipulated to increase MF by reducing MI in pasture-based AMS were identified. Clearly more research is needed to quantify the effects of these management strategies on animal and whole system performance.

Several conclusions can be drawn from the review of the published literature in the field.

First, it has been proven satisfactorily that AMS can be incorporated into pasture-based production systems typical of those in Australia and New Zealand, without compromising pasture utilisation. Despite some potential advantages and disadvantages that managing these systems could have, it is clear that it represents a completely new way of farming.

Second, research results of the combination of automatic milking and grazing show a wide range in MF achieved. In pasture-based AMS average MF is lower (MI is higher) in comparison to indoor-based AMS. Increased MF (or lower MI) is associated with greater daily milk yields. Additionally, there is a higher variability in these 2 key indicators within and between cows and throughout lactation. The persistency of MF throughout lactation of cows in pasture-based AMS has not been reported previously. Furthermore there is a need to quantify the effect of different MI on milk yield in pasture-based AMS, together with factors identified as being associated with MI.

Third, the higher synchronisation of activities typically encountered with grazing dairy cows, together with the fact that they concentrate grazing activity during daylight, explains the low cow traffic and low frequency of dairy visits during the early hours of the day. This contributes to the relatively lower system utilisation achieved in these systems in comparison to indoor-based AMS. Any management practice that could increase cow traffic is likely to have a positive impact on MF and system utilisation, although care should be taken not to compromise or negatively impact on any aspect of cow welfare. Changes in feed location (before or after milking) or offering access to 3 pasture allocations in any 24 h period could be examples of such management practices.

Additionally, given that grazing cows are comfortable performing their main activities (eating, ruminating and idling) at pasture and that feed is the most reliable incentive to manipulate cow traffic in AMS, attention needs to be given to pasture and supplement management. It is expected that an increase in the number of daily pasture allocations, each smaller in size, with one of those allocations being available during night time will increase cow traffic and therefore MF. Furthermore, managing the location of supplements by providing access to them before milking (as opposed to after milking), could create a stronger incentive for cows to walk voluntarily from the paddock to the dairy to get milked, therefore reducing MI.

There is a need for improved understanding of feed allocation management, which in turn would allow for new recommendations to be made regarding feed management and their likely impact on cow traffic, number of cows that require fetching and consequently MF. An in-depth understanding on how different management decisions in pasture-based AMS such as milking permission settings and cow traffic routines affect cow traffic and behaviour is required if significant and positive impact on MI and MF are to be realised without affecting animal welfare. Those findings could help to develop sorting
criteria to manage large herds in a differential way. If this were achieved, higher milk production could be achieved from grazing cows managed in pasture-based AMS, which could make the technology more attractive and enhance future adoption.

Conflict of interest statement

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