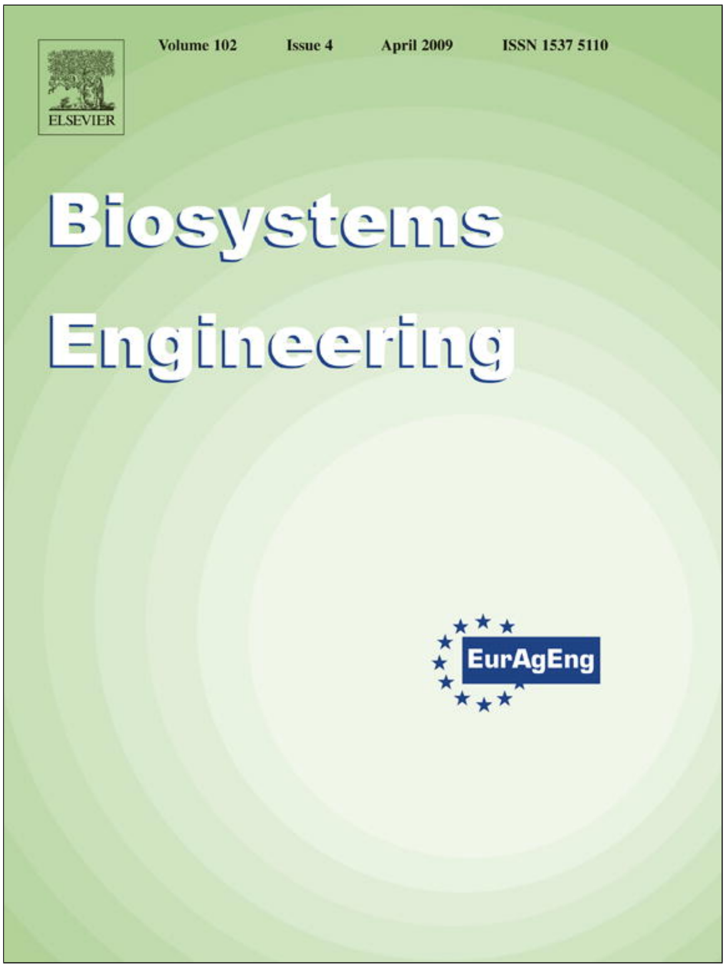
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Simulating the hierarchical order and cow queue length in an automatic milking system

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The effect of cow hierarchical order on cow queue length in an automatic milking system (AMS) was quantified using a validated simulation model.

A typical herd of 67 Israeli Holstein–Friesian cows was observed during 3 months (15 000 milkings, June–August 2006). Milking data were quantified in terms of a gamma probability distribution, which is an input to the simulation model. The herd population was divided into three hierarchical ranks; the lower-tenth percentile (10th percentile) comprised the ''lowest-ranked cows'', e.g., heifers, those with leg or hoof problems, or weaker animals that could not fight their way to the robot. A low-rank cow would wait until the queue had cleared before it entered a milking stall. A dominant cow (the upper 10th percentile) would not wait in a queue, but would push aside the lower-ranked cows until it reached the head of the queue. Within a rank, the cows enter a robot according to their arrival sequences.

Two typical days were simulated: (1) a regular day on which the cows arrived randomly throughout the day and night, (2) a crowded day caused because the robot has been stopped or blocked for a certain period, or all the cows pass through the robot to reach the pasture.

The use of a simulation model allows for full repeatability, so that a long experiment can take only few seconds of computer simulation time. It also enables parameters that are difficult to control in reality to be controlled. The results showed that that social competition between cows influences the timing of visits to the robot i.e., the cow milking frequency. Low-ranking animals generally have to wait longer than dominant animals before they get access to the robot. The simulations showed that during a regular day a low-rank cow waited 68.9 min in the queue, compared with only 10 min for a middle-rank animal, and 3.5 min for the dominant rank. On a crowded day, an average middle-ranking cow queues for 93.5 min while a low-ranking cow waited about 412 min. Introducing a software feature that prevented return milking before 80% of the cows have milked reduce the length of queue by 1 h.

1. Introduction

The adoption of milking robots is spreading rapidly. A study of large robot manufacturers and milk recording organisations (Ilan Halachmi, personal communication) showed that over 5000 robots were estimated to be in use in 2006 in north-west Europe, Italy, Canada, Japan and Israel. The switch to robotic-milking requires farm management practices to be adapted.

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Understanding the cow behaviour in relation to robotic-milking is therefore essential. However, uncontrolled parameters found on real farms can only be analysed effectively using simulation studies. Higher milking frequency (MF) in the robot increases milk yields and consequently accelerates the return on the investment.

The MF of a robotically milked cow is determined by: (1) the willingness of the cow to attend a robot stall; (2) the length of queue in front of the robot. The behaviour of cow queues during steady-state situations, on a ‘‘regular day’’, is well-documented (Halachmi, 1999; Halachmi *et al.*, 2003; Svennersten-Sjaunja & Pettersson, 2008). The behaviour of cow queues during non-steady-state situations, such as the so-called ‘‘crowded day’’, is hardly mentioned in the literature. The original aspect of this study was to deal with queue length during a crowded day. A crowded day relates to the assumption that all the cows present themselves for milking within a short period. This situation can occur on a day where the system has been down for repair and maintenance or a situation in which all cows want to leave the barn to go to pasture but are forced to leave *via* the robot (Ketelaar-de Lauwere *et al.*, 1999).

In farm experiments, the effect of crowded days is not obvious: (1) the economic losses can be large and long experiments can be costly; (2) the recovery time of the herd behaviour following only few hours of robot down-time can be long; (3) a cow can wait outside the queuing area and sneak into the robot without encountering any queue and not be counted as being in a queue; (4) the social order in a large herd is not easily quantified, requiring long tiresome observations. However, the effect of crowded days can be easily examined in simulation experiments.

In competitive situations, in which group-housed animals are fed only one at time, low-ranking cows generally have to wait longer than dominant cows before entering a feeding station (Wierenga & Hopster, 1991; Livshin *et al.*, 1995). On a regular day, Hopster & van der Werf (2000) reported waiting times of 5–175 min, with occasional examples of 2 h and more; they found that the number of animals waiting to enter a feeding stall varied from zero to 7. The average varied from 0.7 and 5.1 animals waiting to enter an unavailable facility. Lack of attention to the relationship between cow social hierarchy and MF has often lead to a long acclimatisation periods being required for robots with some robots being returned to the manufacturers, with the consequent economic losses to the farmer.

Queue length is determined by matching capacity of the robot with the required number of milkings (i.e., the sum of the individual cow MF). High MF together with low-robot capacity results in queues, and *vice versa*. Long queues in front of a robot may increase MF (herd behaviour) or alternatively slow down the visits to the robot from cows that prefer to avoid queuing. Previous studies investigated other influences on the cow MF: the attractiveness of the feed in the robot (Halachmi *et al.*, 2005, in press), farm management practices (Rousing *et al.*, 2006), farm design (Halachmi, 2004): cow traffic (Hermans *et al.*, 2003), and the walking distance from the pasture (Ketelaar-de Lauwere *et al.*, 2000; Woolford et al., 2004; Sporndly & Wredle, 2005). The interaction between cow social hierarchy and queuing has been mentioned through the years in the scientific literature (Rossing *et al.*, 1997; Stefanowska *et al.*, 1999; Hogeveen *et al.*, 2001; Hermans *et al.*, 2003; Melin *et al.*, 2006, 2007). However, because of the afore-mentioned difficulties in making replicated measurements during crowded days, the quantification of the influence of cow hierarchal order on the queuing has not reported in the scientific literature. We believe that simulation can fill that gap.

Robot manufacturers provide a wide range of software capabilities but their implementation depends on the cow behaviour. For instance, if a farmer sets 5 milkings d^{-1} for a cow that provides around 60 l d^{-1} at 0–60 days in milk (DIM), but if this cow arrives only three times per day, it will be milked only three times per day. On the other hand, if the farmer sets milking at three times per day but the cow arrives five times, it will be rejected twice and will actually be milked only three times, as explicitly set by the management software. If the robot capacity is limited, a farmer has to decide which cows will be milked frequently (five or six times per day) or rarely (twice per day). The MF affects milk yield, because milk synthesis rates are greatest immediately after milking, and decline with time. During the early stages of lactation, in order to develop secretory cells the MF may be high but the energy balance of the cow (feed intake, and body condition or body weight) should also be monitored. At later stages of lactation the MF may be set to 2 for individual cows if the milk yield is low; if the cow provides ‘‘skinny milk’’ (with low fat and protein percentages); if the milk flow (l min^{-1}) is slow; if the somatic cell count is high, or according to the cow's physiology and health, body condition, and body weight fluctuations. Use of a ‘80% herd factor’ means that a cow should wait until, e.g., at least 80% of the herd has been milked before it can be milked in a robot stall again. Unfortunately, farmers, advisors and local agents for robot suppliers are often not aware of the importance of the herd factor, because, although it exists as an option in robot software, it often remains unmodified.

Simulation models are often used in the design and operation of complex systems such as production floors, logistic systems, car manufacturing, banks and super markets. Simulation models have been developed for dairy farming (Thomas & Delorenzo, 1994; Burks *et al.*, 1998; Teague & Foy, 2002) but they do not examine robotically milked diary cows. Halachmi (2000) described the model building process and model equations for a robotic-milking oriented farm. In a validation study, Halachmi et al. (2001) compared the data from simulations with that from robotic farms. The hypothesis that the simulation model appeared to be a valid and an accurate representation of the real system under commercially feasible conditions was tested statistically and was not rejected at $\alpha = 2.5\%$ (97.5% confidence level). It was concluded that the model was a practical design tool that enables the designer to optimise facility allocation and barn layout. Halachmi (2004) described the model implementation under hot climate conditions and described how the model assisted five farmers in the inclusion of robots in each farm situation, However, the relationship between cow social hierarchy, queue length and MF has not yet been addressed in a simulation study of robotically milked cows.

Therefore, the objective of this study was to quantify the effects of social order on cow queue length in an automatic milking system (AMS) by using the validated simulation model developed by Halachmi (2000).

2. Materials and methods

2.1. Animals

The study involved measuring 67 Israeli Holstein–Friesian cows, characterised as follows (mean ± standard error (SE)): lactations – 2.42 ± 0.33; DIM – 142.2 ± 0.47; daily milk yield – 34.6 ± 0.30 kg; body weight – 555 ± 8.2 kg; and MF (milkings d^{-1}) – 3.13 ± 0.05. Eleven cows were in 1st, lactation, 23 cows were in 2nd lactation, 11 cows in 3rd lactation, 10 cows were in 4th lactation the others were older. Thirteen cows were 8–90 DIM, 20 cows 91–150 DIM, eight cows were 151–210 DIM, and 26 cows were more than 211 DIM.

All the cows were more than 8 d into at least their 2nd lactation in the AMS and were, therefore, thoroughly familiar with the system. The data acquisition period lasted 3 months, from June to August 2006, and included 15 052 milkings. The farm is owned by Kremer family, located near the Sea of Galilee, north-east Israel. The cows were fed according to the usual practice in Israel; the detailed composition of the feed was as described by Halachmi *et al.* (in press). All the cows received a diet containing 19.9 kg (dry matter – DM) of a mixed ration that was distributed along the feeding lane, plus a supplement of pelleted additive supplied in the robot and in the concentrate self-feeder. The farm design enabled the cows to move freely between the feeding lane and resting areas. The cows visited the AMS voluntarily, being motivated to visit the robot as the only way of accessing the pellets, either in the robot or in the self-feeder behind it. The cowshed was designed to hold 75 cows in milking, with 20 m^2 per cow, and was equipped with a cow-cooling system near the robot. The farm design was described previously (Halachmi, 2004, see page 773, farm E); it was the first open, non-free-stall cowshed reported in the scientific literature that was specifically designed for AMS. The robot was manufactured by Lely Industry (The Netherlands). Every day at 0600 a basic mixture was distributed by a mixer wagon. At 0530, and again between 1200 and 1300, the farm workers led in the few cows (2 or 3 cows d^{-1}) that had not visited the robot for more than 8 h. Robot utilisation during the experiment was 0.84 on average; on crowded days it reach 0.89. The maximum MF of any cow, set in the robot software, was five times per day. Average milking duration was 5.16 min (standard deviation (STD) = 1.99); the fitted distribution function was

$$\text{milking duration(min)} = (1.5 + \text{gamma}(0.925, 4.75)) \tag{1}$$

where gamma is the gamma distribution described by Banks (1998). The individual average milk yield was 13.08 kg milking^{-1} (STD = 3.36), and the average milk flow was 2.82 kg min^{-1} (STD = 1.01).

2.2. Model building

A modular approach is the basis of this simulation model (Halachmi, 2000). The system (or barn) is broken down into five modules whose interactions generate the cow behaviour; they are the barn facilities (milking robot, concentrate feeder, forage lane, water troughs and laying area). Additional components can be added to the model as needed. The model addresses processes, i.e., the flow of cows through the barn facilities is studied and represented graphically. Cows are the primary entities in the model, and each has six important attributes: a number, a picture, a most recent milking time, and a most recent concentrate consumption time, individual milk yield, and social priority (dominance in the herd). In the animation, vivid colours indicate a cow's state: a green cow is occupying a facility, eating, being milked, or resting; a blue cow is in transit i.e., either walking between facilities or idle and a queuing cow is red.

The model equations were described by Halachmi (2000), the model validation was carried out by Halachmi *et al.* (2001), model implementation in the field of farm design and operation was reported by Halachmi (2004). The adaptation of the model to cow social hierarchy vs. cow queue length, the current question, is described below.

2.2.1. Model logic, assumptions, and implementation

The primary simulated entity is a cow, and the simulated resource is the robot. The herd population was divided randomly into three sectors; the lower-tenth percentile (10th percentile) comprised the "lowest-ranked cows" – those of the lowest-hierarchic order (rank), e.g., heifers, those with leg or hoof problems, or weaker animals that could not fight their way to the robot. A low-rank cow would wait until the queue had cleared before it entered a milking stall. A dominant cow would not wait in a queue, but would push aside the lower-ranked cows until it reached the head of the queue. Within a rank, the cows enter a robot according to their arrival sequences. For instance, if more then one dominate cow arrives; all the dominant cows are assumed to enter the robot on the basis of their arrival – first in first out. Then, after all the dominant cows have left, the middle-ranked cows will start entering the robot. Then, after the queue has cleared, the lower-ranked cows will enter. Since the total number of cows in the herd that was milked by one robot was 67, therefore there were six or seven lowest-rank cows and six or seven highest-rank cows in the herd. The robot self-cleaning interval was 8 h, with each cleaning taking 0.5 h, i.e., a total of 1.5 h d^{-1}. The robot utilisation in the simulation was taken as the farm-observed value of 0.84. Since 84% robot utilisation means that the robot was inactive for 3.84 h d^{-1}, a low-rank cow had enough time to sneak into the robot without encountering any queue. The simulation covered 100 d in 1-min time-steps. The days were independent identically distributed (IID). The model was implemented with Arena 10 simulation software (Rockwell Automation, Inc., Milwaukee, WI, USA, www.rockwellautomation.com).

2.2.2. Model inputs

The robot-service-time (milking duration) was taken from measured values and presented in Eq. (1) above. Number of milkings per day was 220 – an average of 3.3 milkings per cow per day, as is common in Israel for this type of farm and robot. Since $24 \times 60/220 = 6.5$ min, the simulated cow arrival rate followed a triangular distribution with minimum = 0; most likely = 6.5 and maximum = 2×6.5 min between arrivals, i.e., zero, one, or two cows arrived every 6.5 min

$$\text{time between arrivals} = \text{triangular distribution}(0, 6.5, 13)\ \text{min} \quad (2)$$

where triangular distribution function is specified by Banks (1998, pp. 158–159), the minimum is 0, the mode is 6.5 min and the maximum is 13 min.

2.2.3. Model outputs

The model outputs were cow queue length in minutes and number of cows waiting in the virtual queue.

2.3. Model verification and validation

The original model from which the robot modules were adapted, had undergone a validation procedure (Halachmi et al., 2001). The simulation model appeared to present a valid and accurate representation of the real system under commercially feasible conditions. This hypothesis was tested statistically and was not rejected at $\alpha = 5\%$ (Halachmi et al., 2001). The required adaptation that was introduced into the model was the robot-service-time distribution function. The goodness of fit of this function (Eq. (1)) was statistically tested: the square error was 0.001367 min, the Chi square test (17 intervals, 14 degrees of freedom) gave $p < 0.005$, and the Kolmogorov–Smirnov test gave $p < 0.01$.

A number of steps were taken to verify that the model after the adaptation was still a reasonable representation of reality. (a) The model repeatedly passed the ''face validity'' test (Pidd, 1992), i.e., several people familiar with the farm at crowded days found that the behaviour of the model mimicked that of the real system. Visual observation on a regular basis identified the lower-tenth and upper-tenth cows and examined their behaviour (actually these observations initiated the idea of simulating this phenomenon). (b) Several consistency checks (Law, 1990) were performed, such as making incremental increases in the herd size (number of cows) and robot down-time hours to confirm that they led to reasonable and steadily increasing values. (c) The model was subjected to extreme-condition tests, such as setting extremely high robot utilisation, and was found to continue behaving reasonably.

2.4. Scenario analysis and statistics

The study involved three state variables: day, herd factor, and cow social hierarchy.

Two typical days were simulated: (1) a regular day where the cows arrived randomly throughout the day and night, according the farm measurement (Eq. (2) above); and (2) a crowded day because the robot has been stopped or blocked for a certain period. In some farms, crowded days are part of the farm routine, the cows stay overnight in the barn and all the cows pass through the robot to reach the pasture in the morning. In the simulation, all the cows arrived at the robot within 1 h. This rush hour represented a simulated crowded day, because either the robot stopped or blocked for a certain period or all the cows would have to pass through the robot to reach the pasture. The crowded day was simulated twice, with and without application of a herd factor.

Herd factor is a software feature that allows a cow to be milked again only if at least 80% of the animals were milked since its previous milking. The purpose of herd factor is to reduce the queue. The states are

(1) {crowded, regular} $\in$ day,
(2) {with, without} $\in$ herd factor. Implemented or devoid of herd factor
(3) {lower, middle, and upper tenths} $\in$ cow social hierarchy

Therefore, the number of combinations is $2 \times 2 \times 3 = 12$ that firms the potential simulated scenarios.

The measure of performance was the cow queue length, in two dimensions: time (minutes, min) and length (number of cows, #cows).

The following scenarios are presented in tables:

Table 1: crowded days, with or without herd factor, number of cows.
Table 2: regular days, without herd factor, lower, middle, and upper tenths min.
Table 3: crowded days, with and without herd factor, lower, middle, and upper tenths, min.

The following statistics were used: mean is the average value, STD is the standard deviation, min is the smallest component and max is the largest component, SE is the standard error. An ANOVA was calculated using SPSS software Chicago, Illinois, USA (www.spss.com). The simulation was stochastic, 100 repeated days were simulated in each scenario. Simulation time-step was 1 min. The farm layout is presented in Fig. 1.

3. Simulation results

Two typical days were simulated: (1) a regular day, (2) a crowded day. The crowded day was simulated twice, with and without application of a herd factor. The measures of performance were the cow queue length (min) and number of cows waiting for a busy robot.

Table 1 – An average cow queue length at a crowded day[a,b] with and without ''herd factor''[b]

	Herd factor[c]		ANOVA	
	With	Without	F (1,198)	p-Value
Mean (#cows[d])	14.5	16.4	80.5	0.000
SE	0.11	1.175		
N	100	100		

[a] Crowded day might occur when a robot has been stopped or blocked for a certain period, or all the cows have to pass through the robot to reach the pasture.
[b] On a regular day, the average queue length was 2.121 cows (STD = 1.25).
[c] ''Herd factor'' is a software option allows a cow to be milked again only if at least 80% of the animals were milked since its previous milking. The purpose of herd factor is to reduce the queue on crowded days.
[d] #Cows = cow queue length, number of cows waiting to enter the robot (so-called ''a queue'').

Table 2 – Cow queue length at the robot on a regular day

	Tenth[a]			ANOVA	
	Lower	Middle	Upper	F (2,297)	p-Value
	Waiting time[b] (min[c])				
Mean	68.9	10.0	3.5	92.04	0.000
SE	6.5	0.40	0.11		
N	100	100	100		

[a] The herd population was divided into three hierarchical ranks; the lower-10th percentile comprised the "lowest-ranked cows", e.g., heifers, those with leg or hoof problems, or weaker animals that could not fight their way to the robot. A low-rank cow would wait until the queue had cleared before it entered a milking stall. A dominant cow (upper tenth) would not wait in a queue, but would push aside the lower-ranked cows.
[b] Waiting time is the cow queue length in min for entering the robot.
[c] Min = cow queue length, waiting time in min.

On a regular day, cow queue length, number of cows waiting to enter the robot (so-called "queue"), was on average 2.121 cows (STD = 1.25) that is the normal, desired situation in robotic-milking based farms. On a crowded day, the herd factor reduced the average queue from 16.5 cows to 14.5 cows (Table 1). Lowest-ranked cows waited longer, according to the social dominance in the herd. It can be seen (Table 2) that during the 100 simulated days, on a regular day, the lowest-ranked cows spent 68.9 min, while middle-ranked ones only 10 min in the queue. Upper-ranked cows spent 3.5 min and waited only if another upper-ranked cows were already in front in the queue. The difference among social ranks was statistically significant (Table 2).

On a crowded day, the waiting time of lowest-ranked cows was about 7 h longer than a middle-ranked cow (412.9 vs. 93.56 min, Table 3).

Without herd factor (Table 4), the waiting time of the lowest-ranked cows was about 1 h longer (472.1 vs. 412.9 min, Table 3). The differences were significant for the lower and middle-ranked cows but not significant for the upper-ranked cows (p-value = 0.602) (Tables 4 and 5).

Fig. 1 – The farm layout and cows on a typical regular day (upper picture) and a typical crowded day (lower picture).

Table 3 – Cow queue length among the three hierarchical ranks on a crowded day with herd factor

	Tenth[a]			ANOVA	
	Lower	Middle	Upper	F (2,297)	p-Value
	Waiting time[b] (min[c])				
Mean	412.9	93.5	5.8	1690	0.000
SE	8.9	1.2	0.3		
N	100	100	100		

[a] The herd population was divided into three hierarchical ranks; the lower-10th percentile comprised the "lowest-ranked cows", e.g., heifers, those with leg or hoof problems, or weaker animals that could not fight their way to the robot. A low-rank cow would wait until the queue had cleared before it entered a milking stall. A dominant cow (upper tenth) would not wait in a queue, but would push aside the lower-ranked cows.
[b] Waiting time is the cow queue length in min for entering the robot.
[c] Min = cow queue length, waiting time in min.

4. Discussion

4.1. *The present study*

4.1.1. *Why simulation?*

A simulation model was applied for several reasons. (1) It enabled 100% repeatability, a situation which cannot be achieved in real-life full-scale AMS experiments. The cows used in any field test are no longer the same as those of the previous year, because of genetic advance and aging, and because year-to-year there are climate and weather changes, and because the ingredients in the feed ration, as well as the farm management practices can change. (2) A long experiment that is in reality might take weeks, months, or years if it covered a full series of lactations for a cow, can take only a few seconds of computer simulation. (3) Simulation enables control of parameters that are uncontrollable in the field. (4) A model can always include enough lower or high ranked cows, whereas in

Table 4 – Cow queue length on a crowded day without herd factor

	Tenth			ANOVA	
	Lower	Middle	Upper	F (2,297)	p-Value
	Waiting time (min)				
Mean	472.1	101.5	5.6	2400	0.000
SE	8.5	1.7	0.3		
N	100	100	100		

Without the application of herd factor (Table 3), the waiting time of the lowest-ranked cows was about 1 h longer (472.1 in Table 4 vs. 412.9 min in Table 3). The differences were significant for the lower and middle-ranked cows but not significant for the upper-ranked cows [412.9 (Table 3) vs. 472.1 (Table 4) F (1,198) = 22.9, p-value = 0.000; 93.5 (Table 3) vs. 101.5 (Table 4) F (1,198) = 15.1, p-value = 0.000; 5.8 (Table 3) vs. 5.6 (Table 4) F (1,198) = 0.273, p-value = 0.602].

a real-life experiment the group is small – up to 70–75 cows per robot – so that the desired social hierarchy may not be obtained.

Because a simulation model of the entire robotic-milking farm was developed previously (Halachmi, 2000, 2004; Halachmi *et al.*, 2000a, 2002) and validated (Halachmi *et al.*, 2001), the robot modules were available for the present study.

4.1.2. *Virtual queue*

Unlike a queue in bank or supermarket, the location of a waiting cow could be anywhere in the barn, rather than in a line in front of the robot. The abstract term "cow queue" in the present study indicates that animals are waiting for an unavailable facility.

4.1.3. *Model logic*

The "black and white" situation of a model is not always realistic. In reality a dominant cow sometimes might wait, and sometimes a lower-ranked cow might run before a dominant one. The model provides insights into the phenomena but not exact values based on individual cows.

4.1.4. *Milking duration*

In the present study fitted distribution function was (1.0 + gamma (0.925, 4.75) + 0.5) min. It included cow identification time and the actual milk flow time. The 0.5 min was added in order to compensate for the time taken by the cow in entering and leaving the milking stall.

4.2. *Comparison with previously published results*

Hopster and van der Werf (2000) reported waiting times of 5–175 min, and found that the average number of animals present in the waiting area before a robot stall varied between 0.7 and 5.1; ranging from 0 to 7 competitors trying to get access to the robot at the same time. These results are comparable with our present findings of 3.5–68.9 min (Table 2) and 2.121 (STD = 1.25) cows (Table 1, footnote b) on a regular day.

The difference could be due to differences in; housing (cubicles vs. open cowshed), feed (Total Mixed Ratio (TMR) ingredients), cow traffic (semi *via* forced routine), space for animals, and cow handling. An important reason could lie in the experimental methodology. Our present study included a measured farm situation, as did Hopster and van der Werf (2000), but then we applied a simulation study to the measured results. The simulation covered 100 days and was repeated with 100% reproducibility. This could not be achieved in a real-life, full-scale AMS experiment where each day might be different.

In the present study the measured average milking duration was 5.16 min (STD = 1.99). Halachmi *et al.* (2000b) also fitted a gamma distribution but reported 8.41 min per milking (STD = 2.53). The previous finding was actually measured in 1997, at the introduction of robots (Halachmi, 1999), so that the difference could be a result of technological advances such as a faster robotic arms, adjustments to the vacuum and pulsation of the robot, and the local farm breeding policy of selecting only the cows that provided the fastest milk flow.

4.3. *Further simulation research*

In the current study, the MF was set constant (as measured 3.13 ± 0.05 milkings d^{-1}) and social hierarchy was the only factor influencing the queue length. In further research, a sensitivity analysis for the influence of changes to MF as a result of the queue may also be of interest. Following a period of robot down-time, the recovery time for herd behaviour lasts long after the robot is repaired. Robot down-time is implemented in the "robot" module with its automatic acquisition of statistics. Therefore, further simulation research examining recovery time can be investigated. In further research, the correlation between cow queue length and length of the robot idle time due to robot mechanical failure should be simulated.

Simulation allows parameters to be controlled that are uncontrollable in farm experiments. In further simulation

Table 5 – Cow queue length among the three hierarchical ranks on a crowded day with and without herd factor

Herd factor		Tenth			ANOVA	
		Lower	Middle	Upper	F (2,297)	p-Value
		Waiting time (min)				
With	Mean (SE)	412.9 (8.9)	93.5 (1.2)	5.8 (0.3)	1690	0.000
Without	Mean (SE)	472.1 (8.5)	101.5 (1.7)	5.6 (0.3)	2400	0.000
ANOVA	F (1,198)	22.9	15.1	0.273		
	p-Value	0.000	0.000	0.602		

$n = 100$.

studies, the changes of hierarchical order or social ranks in the course of time can be simulated and studied.

In further research, the correlation between cow queue length and MF should be investigated. They were not simulated here because this study focussed on understanding the influence of the cow social order.

5. Conclusions

Based on the data measured in the farm and the model assumptions, this simulation study suggests that a lower-ranked cow might wait for an average of 68.9 min, compared with 10 min for a middle-ranked cow. In the case where all the cows queued in front of the robot, a low-ranked cow might wait for an average of 412.9 min while a middle-ranked cow for 93.5 min. If return milkings are allowed only after 80% of the herd already being milked (so-called ''herd factor'') the cow queue length is shortened by 1 h. These results suggest that activating the cowherd factor in the robot software should be recommended. Planned further research should measure the exact number of low-ranked cows in the hierarchy, and enable optimisation of the herd factor value.

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