Increasing economic profit of dairy production utilizing individual real time process data*

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Abstract

Automation of feeding and milking enables application of individual cow settings for concentrate allocation and milking frequency. Currently available systems do not derive these settings from real feed efficiencies and milking characteristics of individual cows in their actual situation, but are based on general knowledge. Parameters that characterize true individual cow responses to concentrates and milking intervals can be estimated continuously from real time process data with dynamic linear models. From these parameters individual optimal settings can be determined, such that maximum profit is achieved given the available robot capacity. This approach is developed and succesfully implemented on a research farm for several months. First results show that a substantial gain in milk yield and in profit is possible.

Keywords: milking frequency, concentrate allocation, dynamic linear models, Bayesian forecasting, individual variation.

Introduction

Economic profit of dairy farms largely depends on milk returns and feeding costs, therefore optimization of feeding and milking has substantial influence on economic profit. Automatic milking and feeding units and decision support systems are increasingly used on Dutch dairy farms (Asseldonk, 1999), enabling the application of individual settings for concentrate allocation and milking frequency. To maximize economic profit the challenge is to continuously optimize individual settings of concentrate allocation and milking frequency for all cows in the herd given the available robot capacity (Hogeveen et al, 2001).

Currently systems of concentrate allocation are based on models (e.g. Van Es, 1978; Zom et al, 2002) that can predict quite accurately the intake and energy requirement of the average cow in a population. Similarly milking interval settings nowadays are based on global knowledge about the average cow in a population. Within animal populations exists considerable variation, both between individuals and within individuals in time, in feed efficiency (Broster and Thomas, 1981) and in milk interval sensitivity (Ouweltjes, 1998). The inability of current models to take account for this variation results in inaccurate predictions of voluntary feed intake (Duinkerken et al, 2003) and milking characteristics of individual cows. This results in suboptimal concentrate allocation and settings of milking frequency. In stead of using models designed for populations of animals, individual allocation of concentrates and setting of milking

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frequency should be based on the efficiency and milking characteristics of the individual cow in its specific situation (Wathes et al, 2005). Databases in management systems contain a treasury of information about the efficiency and performance of each individual cow, but up to now methods that effectively estimate actual individual responses from real time process data are lacking.

In our research dynamic linear models (DLM), developed by West and Harrison (1997), are used for on line estimation of individual parameters that describe feed efficiencies and milking characteristics. Based on daily parameter estimates and actual feed and milk prices the optimal individual settings of milking frequency and concentrate allocation are determined such that maximum economic profit at herd level is obtained.

Materials and methods

<u>Traditional method of milking and feeding on the High-tech farm</u>

The development and implementation of the system took place on a high tech research farm in Lelystad, the Netherlands. This farm is equipped with a robotic milking system and a robotic feeding system for individual feeding roughage-concentrate mixtures. This farm on average had 66 Holstein Frisian cows in milk, with a milk production level of 29.8 kg per day and an average milking frequency of 2.5 times per day in the year preceeding this study. Every three weeks milk samples of individual cows are taken for analysis on fat, protein, urea content and somatic cell count. The cows are milked with a single unit Lely Astronaut® automatic milking system (AMS) and remain indoors year round. Milking start time, milking duration and milk yield are recorded at each milking. The AMS is equipped with manufacturer software to determine whether cows visiting the milking unit are to be milked or not. Individual production level and lactation stage are the main criteria to determine preferred settings for milking frequency. Different settings are applied for heifers and cows. Fixed interval thresholds are set for fetching. Cows with too long milking intervals are fetched three times per day.

Cows are individually fed roughage-concentrates mixtures using a Lely Atlantis® robotic feeder (RF). The ration consists of maize silage, grass silage and soy bean meal, supplemented with a commercial compound concentrates. Between 10 days before and 90 days after calving the ratio between maize silage, grass silage and soy bean meal is 13:4:3 on a dry matter basis. Beyond 90 days after calving the proportions of maize silage and soy bean meal in the ration are gradually reduced to zero in the last trimester of the lactation. Body condition score determines the reduction pattern. The cows are given unrestricted access to the RF, so the intake of concentrates-roughage mixtures is ad lib. Intake of the roughages and concentrates is recorded individually at each meal. Mixtures contain only small amounts of concentrates, so that most of the concentrates are fed individually in the AMS. Concentrate allocation is calculated as the difference between energy requirement and intake, divided by the energy content of the concentrate. Energy requirement is calculated with the (net-) energy system (van Es, 1978). Energy intake is calculated from the predicted feed intake and the energy content of the diet according to the method of Zom et al, (2002). During peak lactation concentrate allocation is limited to a maximum of 12 kg day^{-1} for cows and 10 kg day^{-1} for heifers.

Precision dairy farming (PDF)

An integrated management system for computer control of milking and feeding are part of precision livestock farming (Wathes et al, 2005) or in precise terms precision dairy farming (Doluschitz, 2003). A schematic overview of the components of PDF is given in figure 1.

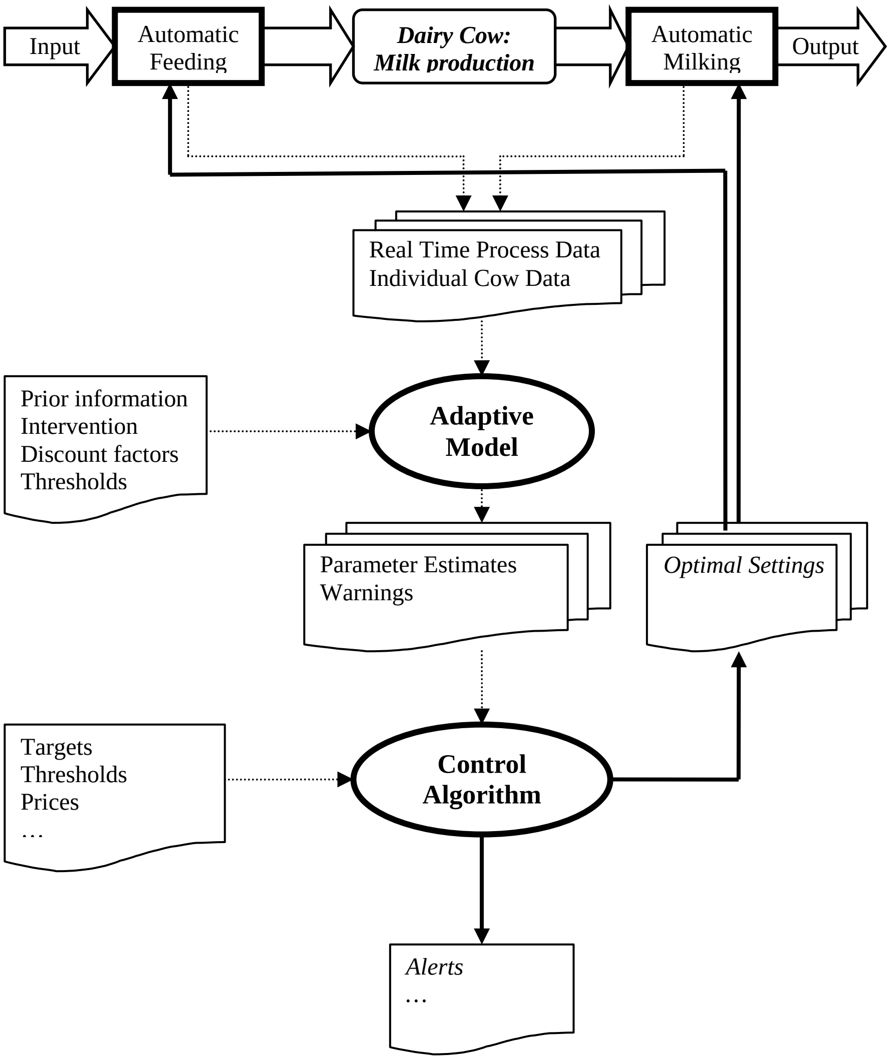

Figure 1 Schematic overview of the components of Precision Dairy Farming (PDF)

Figure 1 is after Aerts et al (2003), but extended to achieve a better understanding of model structure and parameters.Vertically the scheme can be divided into three sections. In the top section three processes are given. Two of them, automatic feeding and milking, are technical processes controlled by computer. Milk production is a biological process and is not directly controlled. In the middle section of the figure the flow of real time process data is given together with the adaptive model for estimation of the parameters that describe the individual response. In the lowest section of the figure the control algorithm is given that calculates the optimal settings of milking frequency and concentrate allocation.

Results and discussion

Outline of the adaptive model

The adaptive model describes relationships between the inputs and outputs of the processes. The model for the relations between the input and output variables is given in the equations (1.1) - (1.3). Real time process data used are milking duration and milk yield per milking and concentrate and roughage intake per visit. The real time process data are accumulated on a daily base. These data are used to estimate the individual dynamic parameters to predict responses of milk yield, milking duration and roughage intake to (changes in) concentrate intake and milking interval. To keep the model compact and simple only low-order linear relations are defined. For simplicity suffixes for time and individual are omitted in the equations.

Milking duration is needed to calculate the total amount of robot capacity that is required and depends on the length of the starting-up period and the milking speed. Total milking duration per cow per day (D) is approximately linearly related to the number of milkings (N) and milk yield (M) per day:

$$D = a_0 N + a_1 M \tag{1.1}$$

with individual dynamic parameters:

- a_0 starting-up period per milking (min.)
- a_1 effect of inverse of milk flow (min. kg^{-1})

Milk yield per milking depends on the length of the preceding interval and production rate. Production rate increases with concentrate intake to a maximum and decreases with increasing interval length (Ouweltjes, 1998). It is not necessary to model the response of milk yield to roughage intake, because roughage is freely available and the effect of substitution of roughage by concentrate on milk production is implicated in (1.2). We assumed that the accumulated milk yield per cow per day (M) is approximately a quadratic response surface to concentrate intake per day (C) and accumulated interval lengths per visit (I_j):

$$M = \left(c_0 + c_1 C + c_2 C^2\right) \sum_j I_j + b_2 \sum_j I_j^2 \tag{1.2}$$

with individual dynamic parameters:

- c_0 intercept or base-level (kg day^{-1})
- c_1 linear effect of concentrate intake (kg kg^{-1} day^{-1})
- c_2 quadratic effect of concentrate intake (kg kg^{-2} day^{-1})
- b_2 quadratic effect of interval length (kg day^{-2})

Finally the intake of roughage in response to concentrate intake needs to be modeled. Roughage intake per day (R) is approximately linear related to concentrate intake (C):

$$R = d_0 + d_1 C \tag{1.3}$$

with individual dynamic parameters:

d_0 intercept or base-level (kg)

d_1 linear effect of concentrate intake (kg kg^{-1})

The adaptive model is compact, it consists only of 3 response variables: milking duration (D), milk yield (M) and roughage intake (R) per day and 4 regression variables: number of milkings (N), milk yield (M), concentrate intake (C) and interval length (I). Per cow per day there are only 8 parameters ($a_0 \ldots d_1$) that describe the influences of milking frequency and concentrate allocation and they have a clear physical and/or biological meaning.

Brief outline of the parameter estimation

The parameters can be estimated on-line from real time process data per cow using dynamic linear models (DLM) based on a Bayesian procedure for on-line estimation and analysis of time series. At the start of each series initial parameter settings (prior information) are set, based on global or specific knowledge about the individual. Subsequently the parameters are sequentially updated, based on historical outcomes of the process. For each set of parameters the adaptation speed is regulated by a fixed discount factor. Values for these factors are normally set between 0.8-0.98.

Disturbances of the process, such as outliers, are automatically detected. If so, warnings are given and automatic intervention takes places to ensure that the model adapts to the possibly changed situation. If the effect of a change in the process is known in advance subjective intervention is possible. Warnings could form the base for alerts to the herdsman, but these are not yet developed. These features make that DLM is flexible and capable of adapting to the complex dynamic processes in animals.

Outline of the control algorithm

The control algorithm calculates individual optimal settings for concentrate allocation and milking frequency from the parameter estimates. The objective is to maximize the daily balance: milk returns minus feeding costs, within the available robot capacity (D_{Max}). Milk returns depend on the individual milk price (π_M) which is affected by milk constitution. Feeding costs depend on the pricing of concentrate (π_C) and roughage (π_R). The optimum concentrate allocation per cow (C_{Opt}) is given by:

$$C_{Opt} = \frac{-\left(\pi_M c_1 - \pi_C - \pi_R d_1\right)}{2\pi_M c_2} \tag{2.1}$$

The optimal milking frequency depends on the available robot capacity (D_{Max}) and the herd size (H). The available robot capacity is limited by system capacity, time needed for regular cleaning and extra cleaning after milking cows with abnormal milk (e.g. mastitis colostrum). Also a certain amount of free time is needed to avoid queuing in the waiting area. The optimal settings are calculated such that milk returns minus feeding costs is maximal on condition that the total milking duration at herd level is less or equal to D_{Max}. The optimal milking interval (I_{Opt}), reciprocal of the optimal milking frequency, is given by:

$$I_{Opt} = \left\{ b_2 \left(\frac{a_1 - \pi_M \gamma\left(D_{Max}, H\right)}{a_0} \right) \right\}^{-\frac{1}{2}} \tag{2.2}$$

with $\gamma\left(D_{Max}, H\right)$ a function that depends on the available robot capacity and the herd size. In this function also other parameters, averaged at herd level, play a role.

The final settings for milking interval and concentrate allocation can not blindly be derived from (2.1) and (2.2) for all cows in the herd. During the first 20 days of the lactation milking intervals are set to 8 hours and concentrate allocation is linearly increased with 0.5 kg day^{-1} up to a 10 kg day^{-1} for heifers and to 12 kg day^{-1} for cows. After day 20 milking interval is kept between 4.8 to 12 hours and the proportion of concentrates in the diet is restricted to 40% of total feed intake. Day-to-day changes in milking frequency are limited to ± 0.5 milkings day^{-1} and changes in concentrate allocation are limited to ± 0.5 kg day^{-1}. At the end of lactation before drying-off, milking frequency and concentrate allocation are gradually reduced. The final settings are derived after combining the above restrictions and the calculated optimal settings.

Implementation and evaluation of the individual dynamic approach

After a period of prototyping the dynamic approach was evaluated between 1-7-2006 and 30-9-2006 on the experimental high-tech farm. Even though the models are defined at day level, calculation and implementation of optimal settings were done weekly. In the evaluation period average herd size was 71.0 cows with an average milk production of 31.8 kg milk/cow/day and 23.5 kg concentrates per 100 kg milk. Total intake was 39.2 kg/cow/day, of which 31.8 kg grass-maize silage and 7.4 kg concentrates. In comparison to the traditional approach especially in the first stage of the lactation more concentrate was given, so the negative energy balance was reduced. An improved negative energy balance is assigned with positive effects on fertility and health (DeVries et al, 1999). The cows maintained a good body condition score.

In the evaluation period the average milking frequency was 2.6 milkings per cow per day and the average total milking duration of the robot was 18.1 hr per day. It turned out that the total milking duration was suitably tailored to the available capacity with regard to the varying herd size. The remaining time (5.9 hr per day) was amply sufficient for cleaning etc. and suggests that it is possible to milk more cows per day. The available capacity was allocated such that the loss of milk production was minimized and did not have disadvantages for fetching. Fetching was regulated at individual level by setting a factor defining the maximum milking interval. Normally this factor is set to 1.3 times the optimal milking frequency. In case of high somatic cell count or milk leakage the factor could be decreased to 0.8 by the herdsmen. Incidentally, e.g. for cows at the end of the lactation, the factor was increased to 1.5. The herdsmen judged the daily amount of fetching as acceptable. The herd performance with these new feeding and milking settings was good.

Prototyping and testing of the system is done on herd level and within the herd it was impossible to create independent groups for comparison with a control to establish reference points. To gain insight in the potential value of our approach we did predict results from both the optimal and traditional settings of concentrate allocation and milking frequency at 2 days in the evaluation period (6-7-2006 and 6-9-2006) for each cow. Figure 2 shows how profit (milk returns minus feeding costs) can be improved with the optimal setting of concentrate allocation. Optimal settings can both be higher as well as lower than traditional settings and in both cases profit can be improved. Figure 3 shows how profit is related to the optimal milking frequency. For most cows the optimal milking frequency is higher than the traditional settings and this also can improve the balance.

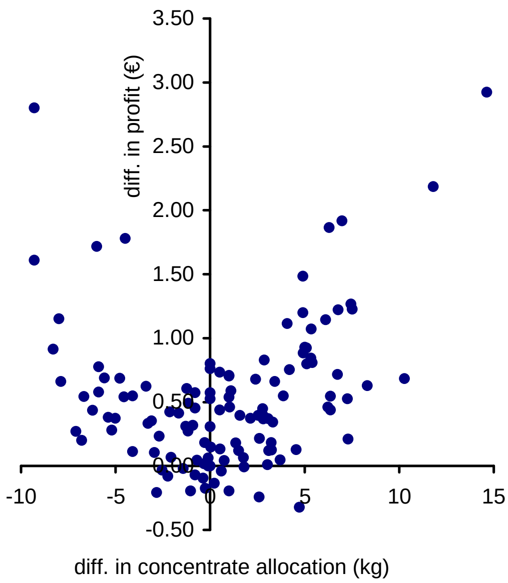

Figure 2 Difference in predicted profit (Y-axis) vs. difference in concentrate allocation (X-axis).

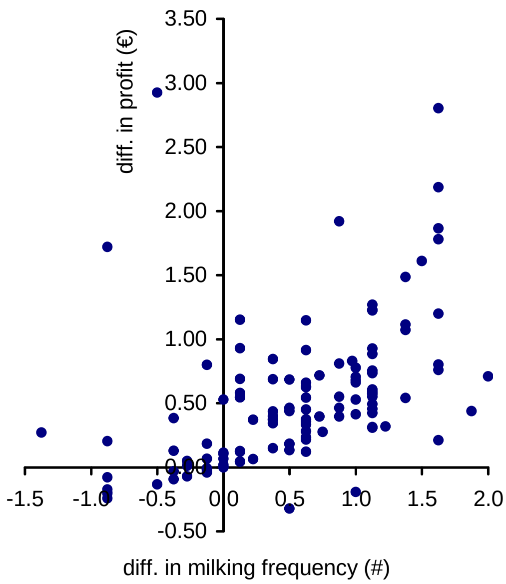

Figure 3 Difference in predicted profit (Y-axis) vs. difference in milking frequency (X-axis).

Averaged predicted results are given in table 1. On average optimal settings for concentrate allocation is 12.4 % higher than the traditional settings, but the roughage intake is not reduced. Optimal settings for milking frequency are much higher (19.9 %) but the increase in milking duration is only (10.6 %). With the optimal settings a more efficient use of the robot capacity is realized and above that there is a substantial gain in milk yield (6.7 %) and in profits (7.5 %).

Table 1 Predicted results from traditional settings of milking frequency and concentrate allocation compared with predicted results from the optimal settings.

	Traditional Settings (a)	Optimal Settings (b)	Absolute difference (b-a)	Relative difference 100(b/a-1)
Milking frequency (# $cow^{-1}day^{-1}$)	2.71	3.25	0.54	19.9 %
Concentrate allocation (kg $cow^{-1}day^{-1}$)	5.7	6.4	0.7	12.4 %
Milking duration (min. $cow^{-1}day^{-1}$)	14.4	15.9	1.5	10.6 %
Roughage intake (kg $cow^{-1}day^{-1}$)	31.3	32.1	0.9	2.6 %
Milk yield (kg $cow^{-1}day^{-1}$)	31.5	33.6	2.1	6.7 %
Balance (€ $cow^{-1}day^{-1}$)	7.23	7.77	0.54	7.5 %

Predicted results may be too optimistic while in practice the animals will not exactly realize the settings. That will be the case both with the traditional settings as with the optimal settings, so we cannot rely on the absolute differences, but the relative differences give a good indication of the benefits of the individual dynamic approach. Implementation of the dynamic system can be achieved with the usual equipment so there is no need for extra investment in hardware.

Conclusion

Individual dynamic optimal settings of milking frequency and concentrate allocation[2] can be successfully deduced from real time process data with relatively simple dynamic linear models (DLM's) that continuously estimate the responses of dairy cows to these settings. DLM offers a flexible estimation procedure. Application of individual optimal settings can result in a more efficient use of the robot capacity and also in a substantial increase of milk yield and profit. The limited robot capacity is efficiently distributed among the cows with regard to the varying herd size.

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[2] We achieved the solutions in 2.1. and 2.2 by mathematical analysis. The solution is nearly optimal; an optimal solution can be achieved by solving the nonlinear programming problem.

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