# Automated monitoring of milk meters

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**Abstract**
Automated monitoring might be an alternative for periodic checking of electronic milk meters. A computer model based on Dynamic Linear Modelling (DLM) has been developed for this purpose. Two situations are distinguished: more milking stands in the milking parlour and only one milking stand in the milking parlour, e.g. in case of robotic milking. In the first case the model is based on a comparison per milking session of the average per stand with the overall average over all stands. The model calculates a stand deviation factor per stand after each milking session. In the second case the model is based on a comparison of the measured milk with the total collected milk. The model calculates a separation term and a deviation factor after each collection to the milk. The measured milk yields of two experimental farms, one with and one without a milking robot, were used to test the model. It was possible to fit the stand deviation factor with the model for the comparison of milking stands. This factor can be interpreted as the relative error per milking stand and per milking session. The results correspond globally with routine control results. The results of the model at the milking robot farm for the comparison of measured and collected milk were hampered by unknown separations. The conclusions of this research are: Automated monitoring of milk meters by a comparison of the average per stand with the overall average is possible. Validation on more farms is wanted. The measured milk yield should be corrected by the stand deviation factor if it is used for management purposes. Automated monitoring of milk meters on milk robot farms by a comparison of the measured milk with the collected milk seems possible, provided that separated milk is recorded properly.

**Keywords:** Dynamic Linear Model, milking stand, milking robot, stand deviation factor

## Introduction

Most dairy cows are milked by milking machines. The milk yield of dairy cows per milking can be measured by electronic milk meters. In 2007, 26% of the dairy farms in The Netherlands was equipped with electronic milk meters (www.stichtingkom.nl). For approval, according to the guidelines of the International Committee for Animal Recording (ICAR, 2007a, 2007b), the milk meters must be checked after installation and every year. These routine controls of milk meters are labour-intensive and costly. Automated monitoring might be an alternative. A computer model has been developed for this purpose.

If there are more milking stands in the milking parlour, one can assume that the averages per milking stand are more or less equal for each milking session. A statistical model is based on a comparison per milking session of the average per stand with the overall average. The milk meter on a specific stand is defect when the deviation is too big.

If there is only one milking stand in the milking parlour, e.g. in case of robotic milking, one can assume that the amount of measured milk is more or less equal to the collected milk. A statistical model is based on a comparison of the measured milk with the collected milk. The milk meter is defect when the deviation is too big.

The objective of this paper is to describe the models used for the monitoring of milk meters and the results of the model on two farms.

## Material and methods

*Milking data*

The measured milk yields of the experimental farm in Zegveld, the Netherlands in the period January 1, 2006 till October 8, 2007 were used to test the model for the comparison of milking stands. On this farm there were on average 82 lactating cows milked twice a day in a milking parlour with eight stands (numbered from 80 through 87, see Figure 1). The milk yield is in general higher for the morning milkings because the intervals are longer then. 106,508 Milk yields are included in this dataset, 875 milkings with zero yield were excluded for the statistical analysis. Mostly there are about 10 milkings per stand for each milking session. The milk meters are checked once a year, routine control reports were available for February 13, 2006 and January 26, 2007.

The measured and collected milk of the experimental farms Zegveld and the ‘high-tech farm’ of ASG in Lelystad, the Netherlands, in 2006 were used to test the model for the comparison of measured and total collected milk. In the experimental period there were 212 collections in Zegveld (same period as above, every two or three days, on average 7187 kg) and 122 collections at the high-tech farm (on average 6001 kg). On the high-tech farm there were 70 cows with on average 170 milkings per day in one milking robot. This data set included 69,189 milk yields, 495 milkings with zero yield were excluded from the statistical analysis. Collection data were not used in the analysis if the difference between recorded and collected amount of milk is more than 2.326 times the standard deviation, as the milk meter are apparently faulty then.

*Model for the comparison of milking stands*

The average milk yield per stand and milking session is calculated over all milkings on that stand. The resulting stand average is compared with the overall average. The deviation will be close to zero for a properly working meter. A Dynamic Linear Model (DLM, West and Harrison, 1989) is based on a comparison per milking session of the average per stand with the overall average. This model is described here:

The deviation of the stand average with the overall average is:

$$Deviation_{ms} = AvKgMilkMS_{ms} - AvKgMilkM_m \quad (1)$$

with:

$Deviation_{ms}$ = deviation for milking session m and stand s (kg);

$AvKgMilkMS_{ms}$ = average milk yield for milking session m and stand s (kg);

$AvKgMilkM_m$ = average milk yield for milking session m (kg).

It is assumed that the stand deviation is a factor relative to the average milk yield for a milking session:

$$Deviation_{ms} = \mu_{ms} \cdot AvKgMilkM_m \quad (2)$$

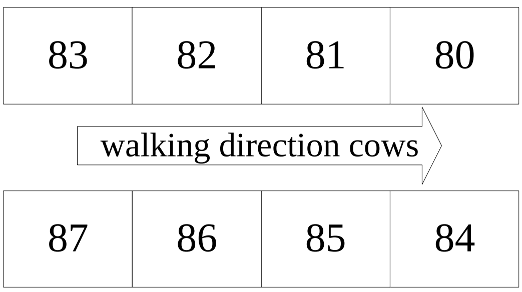


Figure 1 Lay-out of the milking parlour of the experimental farm in Zegveld with eight milking stands numbered from 80 through 87.

The stand deviation factor $\mu_{ms}$ will be close to zero if the milk meter is recording correctly, positive if the milk meter recordings are too high or negative if the milk meter recordings are too low.
A formulation with an observation equation and system equation is needed for the application of DLM (Dynamic Linear Model). The observation equation is:

$$Y_t = F_t^{'}\theta_t + \upsilon_t,\ \upsilon_t \sim N[0,V_t] \quad (3)$$

with:
$Y_t$ = observation vector;
$\theta_t$ = parameter vector describing the state of the system;
$F_t$ = design matrix describing the relation between the state and the observation;
$\upsilon_t$ = observational error.

The system equation is:

$$\theta_t = G_t\,\theta_{t-1} + \omega_t,\ \omega_t \sim N[0,W_t] \quad (4)$$

with:
$G_t$ = system matrix, describing the relation between the current and the previous state parameters;
$\omega_t$ = system error.

This model is applied for each stand s and milking session m ($t \equiv m$) with the following implementation:
$Y_m = Deviation_{ms}$ the observed deviation for stand s and milking session m (kg);
$\theta_m = \mu_{ms}$ the stand deviation factor;
$F_m = AvKgMilkM_m$ average milk yield for milking session m (kg);
$G_m = I$ identity matrix, assuming that the state is locally constant.

With this implementation, the observation equation (3) states that the stand deviation factor of the overall average is observed. The system equation (4)states that it is expected that the factor does not change in time. The model estimates the stand deviation factor per stand after each milking session. An alert is given when the stand deviation factor differs significantly from zero. This model is fitted with a special developed procedure within the statistical package Genstat (Payne *et al.*, 2006) for analyzing DLM's. The number of milkings is used as a weighting factor, discount factors are used to regulate the adaptation speed. The discount factors have been chosen such that the likelihood of the fitted model is maximal and the serial correlation of the observation errors is low.

*Model for the comparison of measured and collected milk*
The above-mentioned model for the deviation per stand is only applicable is there is more than one stand. A milking robot farm can be a one-stand farm if there is only one robot with one stand. Then a model for the comparison of the milk yields, as recorded in the milking parlour, with the milk collections, as recorded by the milk collection truck, is used. The deviation of the recorded amount of milk with the collected amount is:

$$Deviation_t = SumMilkYield_t - SumCollected_t \quad (5)$$

with:
$Deviation_t$ = deviation for collection t (kg),
$SumMilkYield_t$ = sum of the recorded milk yields for collection t divided by the time since last collection in days (kg),
$SumCollected_t$ = sum of the collections for collection t (usually one) divided by the time since last collection (kg).

It is assumed that the deviation consists of an absolute and a relative error:

$$\text{Deviation}_t = \alpha_t + ß_t \cdot \text{SumCollected}_t \quad (6)$$

The first term, $\alpha_t$ is the absolute error and can be considered as the amount of milk that does not reach the milking tank (because of own use, separation or other reasons). The deviation factor $ß_t$ is the error relative to the collected amount. This factor will be close to zero for a properly working meter, positive if the milk recordings are too high and negative if the milk recordings are too low. A formulation with an observation equation and system equation is needed for the application of DLM, see Equation (3) and (4).
This model will be applied for each collection t with the following implementation:

| | |
|---|---|
| $Y_t = \text{Deviation}_t$ | the observed deviation for each collection; |
| $\theta_t = (\alpha_t\ \beta_t)^T$ | the state is formed by the two parameters; |
| $F_t = (1\ \text{SumCollected}_t)^T$ | the sum of the collections is included in the design matrix; |
| $G_t = I$ | the system matrix is the identity matrix, assuming that the state is locally constant. |

The observation equation (3) now states that the observation (deviation) equals the sum of a 'fixed' part, the separation term $\alpha_t$, and a part depending on the amount of collected milk by the deviation factor $ß_t$ plus an observation error (with zero average). The system equation (4) states that it is expected that the separation term $\alpha_t$ and the deviation factor $ß_t$ do not change.
This DLM model can be fitted with the statistical package Genstat (Payne *et al.*, 2006), as described in the model for the comparison of milking stands. The model estimates separation term and the deviation factor after each collection to the milk factory. An alert is given when the separation term or the deviation factor is too big.

## Results

*Model for the comparison of milking stands*
The model is fitted on the deviations of the stand average with the overall average for the experimental farm in Zegveld per stand and milking session. It was possible to estimate the stand deviation factor with the model for the comparison of milking stands. The stand deviation factor can be interpreted as the relative error per milking stand and per milking session. The resulting stand deviation factors per stand in the experimental period are depicted in Figure 2. The zero level is mostly included within the 95% confidence interval of the stand deviation factor, with stand 82 as an exception to this rule The results correspond globally with the results of two checks. The milk meter at stand 82 was found faulty in the second check; this was signalled by the model several months earlier.

*Model for the comparison of measured and collected milk*
The model is fitted to the deviations between the measured and collected milk for the experimental farms Zegveld and the high-tech farm. It was possible to estimate the separation term and the deviation factor. The results for Zegveld are depicted in Figure 3 and for the high-tech farm in Figure 4. The separation term and deviation factor for Zegveld does not differ significantly from zero (Figure 3), indicating the milk meter equipment is performing well in general. The results of the model at the high-tech farm (Figure 4) for the comparison of measured and collected milk were hampered by unknown separations: Separated milk, e.g. from cows treated for mastitis was measured by the milk meter but of course not collected. These separations were not recorded. The model shows that there were deviations between measured and collected milk, these could be explained by the separated milk.

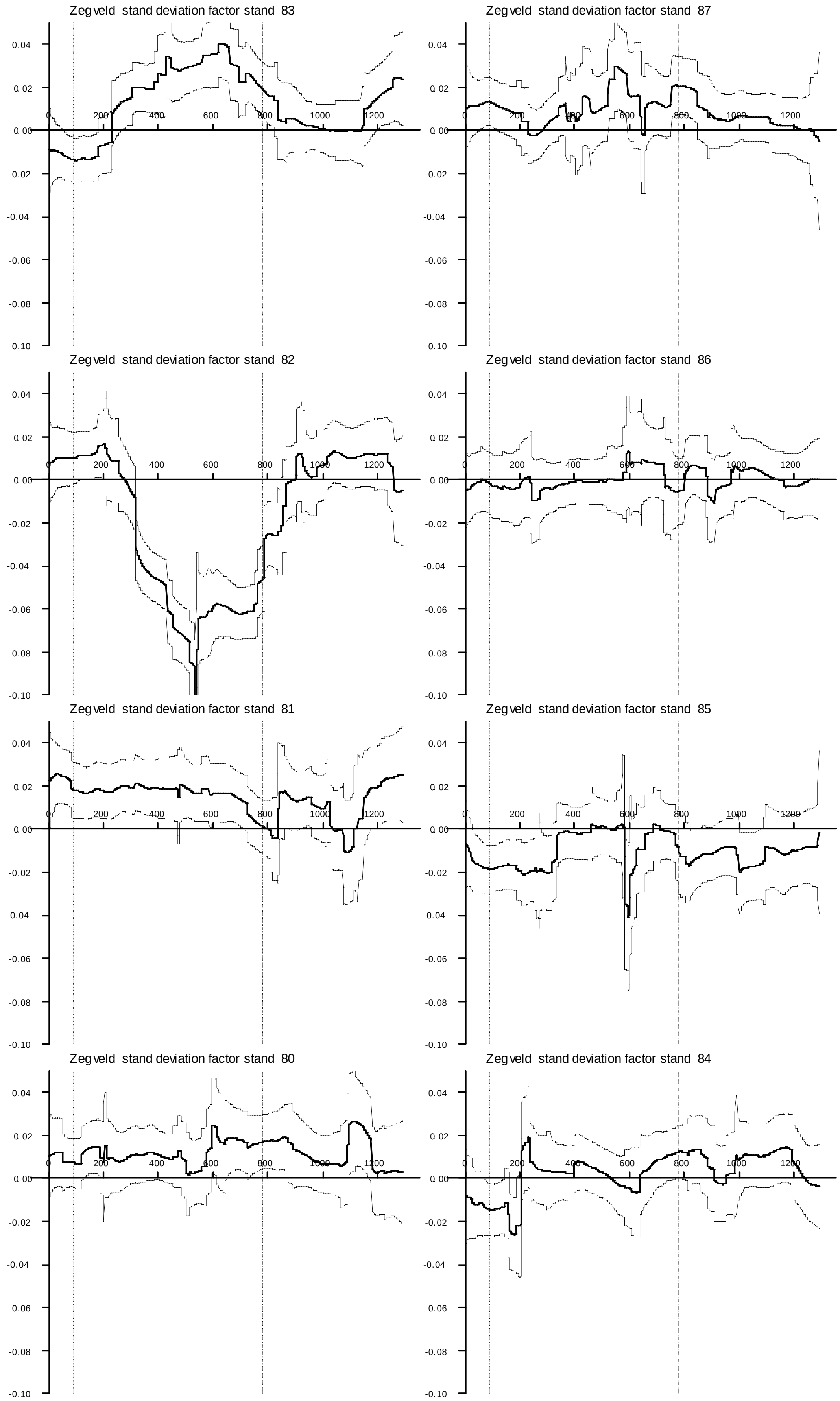


Figure 2 Stand deviation factor with 95% confidence interval per milking session for each milking stand of the experimental farm in Zegveld (NL); vertical lines indicate checking dates.

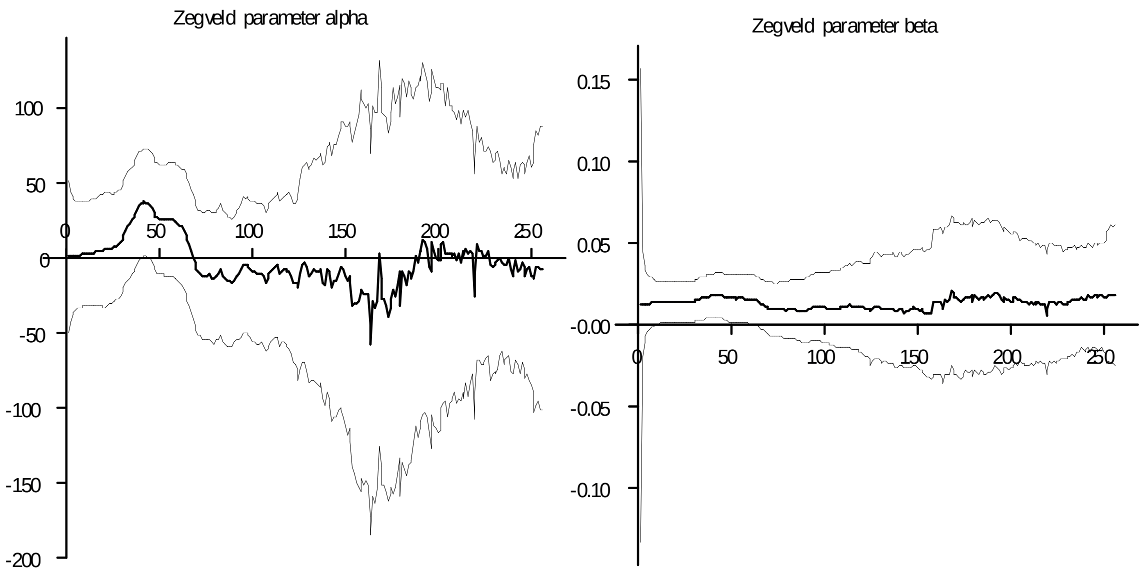


Figure 3 Separation term α (left) and deviation factor ß (right) with 95% confidence interval per collection for the experimental farm in Zegveld met 95% with collections 1-1-2006 and 8-10-2007.

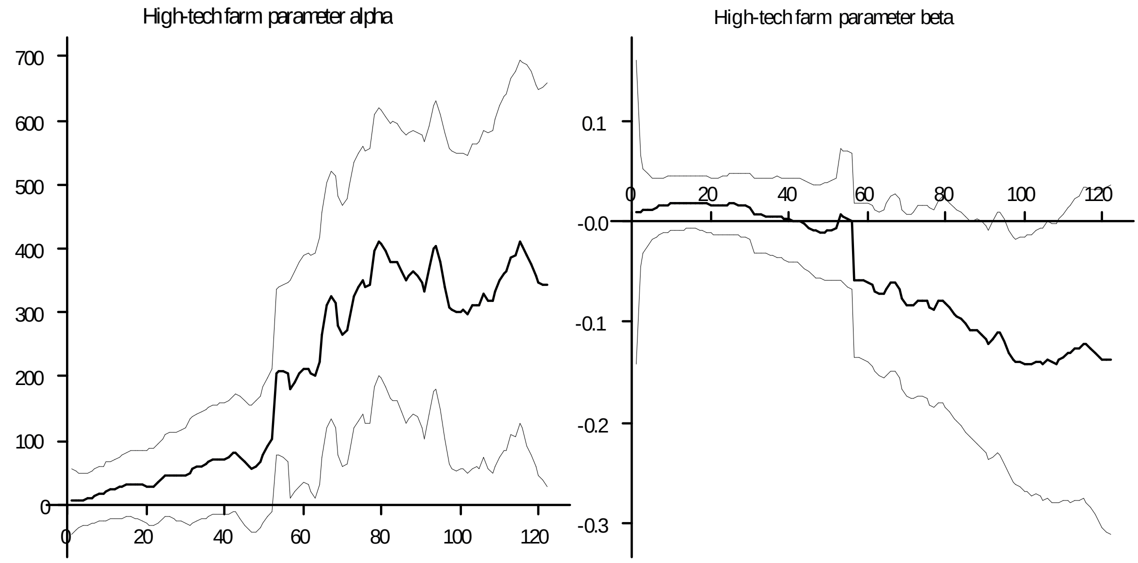


Figure 4 Separation term α (left) and deviation factor ß (right) with 95% confidence interval per collection for the experimental farm in Lelystad met 95% with collections during 2006.

## Discussion

*Model for the comparison of milking stands*

All non-zero milk yields were included in the analysis. It may be considered to exclude very small milk yields (e.g. less than 5 kg) as these indicate that the milking failed or the cow is ill, but is not a clue for milk meter problems. It is possible to overcome this effect by including the expected milk yield per cow and looking at the differences between expected and measured milk per cow and per milking (as in Wendl *et al.,* 1992 and in Umegard and Obermüller, 2004). But then cow identification and cow number registration is needed, as well as a model for the expected milk yield per cow. This all restricts the applicability of the monitoring model. In the proposed approach only milk yield and stand number are needed per cow and milking.

It is assumed that the cows are distributed randomly over the milking stands. It is known from literature (Grasso *et al.*, 2007; Hopster *et al.*, 1998; Paranhos da Costa and Broom, 2001; Tanner *et al.*, 1994) that this is not always fully true. But these effects do not seem to have a major effect on the monitoring results. The model will not work if the cows are divided over the stands based on production characteristics.

The deviation of the milk meters is assumed to be proportional to the yield (Equation 2). The results confirm this assumption.

The results of the analysis depend on the discount factors used. It is not likely that the optimal choice of discount factors will be farm-dependent. But performing a similar exercise on other farms is recommended.

The annual checking of the milk meters in practice is not precise enough to serve as a golden standard for the monitoring model results. The control results are in accordance with the model results, but the differences have not been analyzed in detail.

Typical for the DLM approach are some features that are favourable for practical application: the training period is short, it is a dynamic approach indicating the timing of disturbances and low computational effort is needed for the updates after each milking.

Outliers are observed by the model and may indicate troubles in the equipment. This feature has not been explored yet.

Intervention is possible in the DLM process, this is reasonable if it is known beforehand that the system has changed due to external influences, e.g. when a milk meter is renewed.

There can be seasonal influences on the milk yield, due to changes in feeding, housing and calving patterns. As expected, these changes do not seem to influence the results found at the Zegveld farm, as the changes do not affect the deviations.

*Model for the comparison of measured and collected milk*

Milk collection intervals vary between two and three days, therefore the intervals are unequal. For a proper modelling equal intervals (days, weeks) are preferred but in this study unequal intervals have been used with the number of milkings as weighting factor to counteract this effect partly.

On a milking robot farm, it is not always evident which milkings are parts of a certain collection as there are no separated milking sessions. The recorded time for a milking can be just before or after the recorded time of a collection. The time recording of the milking and the collections should be synchronized. The linking of milkings and collections should be clear for a proper application of this model.

The amounts of separated milk should be recorded, if the separated milk is included the measurements of the milk meters. That makes it possible to compare the collected milk with the measured minus separated milk.

A similar approach is also suggested by Eriksson (2002) but the modelling approach is left open by him.

## Conclusion

The conclusions of this research are:

- Automated monitoring of milk meters by a comparison of the average per stand with the overall average is possible. Validation on more farms is wanted.
- The measured milk yield can be corrected by the stand deviation factor if it is used for management purposes.
- Automated monitoring of milk meters on milk robot farms by a comparison of the measured milk with the collected milk seems possible, provided that separated milk is recorded properly.

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**References**

Eriksson, J., 2002. Improvement of milk measurement and milk collection. Patent WO 02/100164.

Grasso, F., De Rosa, G., F. Napolitano, Di Francia, A., Bordi, A., 2007. Entrance order and side preference of dairy cows in the milking parlour. Italian Journal of Animal Science, 6 (2), pp. 187-194.

Hopster, H., van der Werf, J.T.N., Blokhuis, H.J.,1998. Side preference of dairy cows in the milking parlour and its effects on behaviour and heart rate during milking. Applied Animal Behaviour Science 55:213-229.

ICAR, 2007a. International agreement of recording practices. Approved by the General Assembly held in Kuopio, Finland, on 9 June 2006. International Committee for Animal Recording (ICAR), www.icar.org.

ICAR, 2007b. Periodic checking of approved and provisionally approved meters. Hints for the sample taker and farmer. International Committee for Animal Recording (ICAR), www.icar.org.

Payne, R.W., Harding, S.A., Murray, D.A., Soutar, D.M., Baird, D.B., Welham, S.J., Kane, A.F., Gilmour, A.R., Thompson, R., Webster, R. and Tunnicliffe Wilson, G., 2006. GenStat® Release 9 Reference Manual.

Paranhos da Costa, M.J.R., Broom, D.M., 2001. Consistency of side choice in the milking parlour by Holstein-Friesian cows and its relationship with their reactivity and milk yield. Applied Animal Behaviour Science, 70 (3), pp. 177-186.

Tanner, M., Grandin, T., Cattell, M., Deesing, M.,1994. The relationship between facial hair whorls and milking parlour side preference. Journal of Animal Science 72: 207 (abstr.).

Umegard, A. and Obermüller, H., 2004. A method for calibration of milk meters in a milking system. Patent WO 2004/028242.

Wendl, G., Zenger, X., Auernhammer, H., 1992. A method for continuous automatic monitoring of accuracy of milk recording equipment. In: Prospects for automatic milking, Ipema, A.H., Lippus, A.C., Metz, J.H.M., Rossing, W., Wageningen (Netherlands): Pudoc Scientific Publishers.

West, M. and Harrison, P.J., 1989. Bayesian forecasting en dynamic models, Springer Verlag, New York.