Economic evaluation of automatic heat detection systems in dairy farming

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Abstract. *Although heat detection makes a relevant contribution to good reproduction performance of dairy cattle, available studies on the economic evaluations of automatic heat detection systems are limited. Therefore, the objective of this article is to provide an economic evaluation of using automatic heat detection. The effect of different heat detection rates on gross margin is modelled with SimHerd (SimHerd A/S, Denmark). The analysis considers all additional investment costs in automatic heat detection. The economic evaluation is carried out on the assumption of two different herds of Simmental cattle with milk production levels of 7000 and 9000 kg and herd sizes of 70 and 210 cows, respectively. Furthermore, we distinguish between two investment scenarios: In scenario 1, only cows are equipped with automatic heat detection, while scenario 2 assumes that cows and heifers are equipped with automatic heat detection. Because some variables are relatively uncertain (heat detection rates; time for heat control), they are modelled with triangle distributions using the Monte Carlo method in @RISK (Palisade Corporation software, Ithaca NY USA). This makes it possible to model a probability distribution for the net returns of investment in automatic heat detection.*

The simulation results show that the net return of investing in an automatic heat detection system ranges in all scenarios from -33 to +111 € per cow and year, with mean values of +6 to +35 *€ per cow and year. In general, the net return is independent of the milk production level assumed. A comparison amongst all scenarios shows higher net returns for bigger herd sizes, due to fixed cost degression effects. Considering all scenarios, the probability of a positive net return of using an automatic heat detection system is 82 %. The economic advantage or disadvantage depends strongly on the current fertility management of a dairy farm without automatic heat detection. Additionally equipping heifers with the system has a strong positive effect on the economy of*

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automatic heat detection systems, due to the resulting reduction in the age at first calving.

Keywords. *Monte-Carlo-Simulation, @RISK, automatic heat detection, dairy cattle, SimHerd, activity sensor*

1 Introduction

Health and a good reproductive performance are a prerequisite for sustainable dairy farming. Among all possible reasons for removal from the herd, infertility is the most frequent. Therefore, early and precise detection of heats is essential due to the fact that about 40 % of the reproduction performance of the herd can be influenced by accurate management (Messner 2010). According to literature, the average heat detection rate via visual monitoring is approximately 55 % (e.g., Firk et al. 2002), in which higher time expenditures enable better rates. This deficit is explained by increasingly shorter duration of heats and less strong intensity of signs of heat because of high milk production (Gasteiner 2014). Heats occur more often at night (Wangler et al. 2005). Additionally, growing farm sizes and thereby, increasing workloads limit the time available for active observation of individual animals in the herd. As a result, sensors for automatic heat detection began to be developed in the 1980s (Mottram 2015). A literature review showed the existence of fragmented information with regard to the use and effectiveness of activity sensor systems in dairy farming. Individual aspects of the decision to employ such technology like purchase price and costs of a missed heat are often considered in isolation. In addition, impacts on management are generally regarded qualitatively and thus, a comprehensive economic evaluation generally is not undertaken.

2 Materials and Methods

Stochastic net return model

The objective of this article is to present an economic evaluation of automatic heat detection systems in dairy operations. The net return (NR) of the investment in automated heat detection is calculated through gross margins (GM) for both sensor-supported and visual heat detection – each expressed as a function of heat detection rate. Additionally, all investment costs in automatic heat detection systems are considered. Since automatic heat detection has an impact on the necessary time for heat control, labor cost is included in the calculation of NR. Labor costs for heat control is included at various rates of 10, 15, and 20 € per hour (see formula 1).

$$NR(AHD) = [GM_{AHD} f(HDR) - (LC * THC_{AHD}) - (VC_{AHD} + FC_{AHD})] \\ -[GM_{visual} f(HDR) - (LC * THC_{visual})] \quad (1)$$

NR = net return; GM = gross margin; AHD: automated heat detection; HDR = heat detection rate; THC = time for heat control; VC = variable costs; FC = fix costs; LC = labor cost

The economic evaluation is carried out based on the example of two herds of Simmental cattle with milk production levels of 7000 and 9000 kg and herd sizes of 70 and 210 cows, respectively. Furthermore, we distinguish between two investment scenarios: In scenario 1, only cows are equipped with automatic heat detection, while scenario 2 assumes that both cows and heifers are equipped. The model SimHerd (SimHerd A/S, Denmark) (see below) is used to calculate scenario-specific GM as a function of heat detection rate. Because values for some variables (heat detection rates and time for heat control) are relatively uncertain, they are modelled based on triangle distributions (table 1) using the Monte Carlo method in @RISK (Palisade Corporation software, Ithaca NY USA). Heat detection rate and time for heat control are included with the defined triangle distributions, making it possible to model a probability distribution for the NR. A correlation between the time for heat control and the heat detection rate of r = 0.96 was determined from literature. We consider this correlation in the case of both visual and automatic heat detection. It is also assumed that the rate of detection of heat will not decrease when dairy farmers invest in automatic heat detection systems. Furthermore, it is assumed that farmers who used to spend more time in the visual case tend to do so when using automated heat detection. Thus, time spent for automated heat control correlates with the time spent for visual heat detection (r = 0.9) in the NR model. An estimated useful life of the sensors of 6 years and an interest rate of 4 % are also assumed. Mean producer prices (e.g., milk, slaughter cows, heifers for sale) from August 2016 to July 2017 in Bavaria, Germany are used to determine the GM. The annual investment costs in Heatime® Pro include the costs for acquiring the sensor and the base accessories, and the implementation and repair costs.

Table 1. Assumptions regarding heat detection rates and time invested in heat control

	heat detection rate, visual [%] [a, b, c]	heat detection rate with Heatime [%] [d, e, f]	time for heat control, visual [h/cow and year] [g, h]		time for heat control with Heatime [h/cow and year] [g, h]	
cows			**70**	**210**	**70**	**210**
minimum	30	59	0.9	0.9	0.4	0.4
mode	55	90	2.4	2.3	1.2	1.0
maximum	90	94	5.2	2.8	3.5	1.7

a: Diskin and Sreenan 2000; b: Firk et al. 2002; c: Roelofs and Van Erp-van der Kooij 2015; d: Holman et al. 2011; e: Silper et al. 2015; f: Reith et al. 2014; g: Michaelis et al. 2013, h: expert assessment and practice report

Model structure SimHerd

The existing SimHerd model simulates the production and state changes of a dairy herd including young stock, and has been used to study various herd management tasks (Østergaard et al. 2005a; Kristensen et al. 2008), as well as the implications of genetic trend for the effect of reproduction management (Ettema et al. 2011) and the derivation of economic value of production and functional traits (Nielsen 2004). In SimHerd, the reproductive state of an animal is defined by age, parity, lactation stage, actual milk yield, body weight, culling status, reproductive status (estrus and pregnancy), somatic cell count, disease status, and a fixed component of milk yield potential. The prediction of current state is made week-by-week for each cow and heifer in the herd. The state of the individual animal is updated, and production and input consumption of the entire herd are calculated. Drawing random numbers from relevant probability distributions triggers individual inherent and lactational milk yield potential and simulates discrete events, such as conception, abortion, sex and viability of the calf, diseases, involuntary culling and death. Production and development within the herd are thus, determined indirectly by simulation of production and change in state of each individual cow and heifer.

Model behavior is controlled by a set of decision variables that define particular production systems and management strategies. Modelled culling and reproduction rates are the key components responsible for the effects of various simulated scenarios on the herd structure. A cow that does not concieve during the artificial insemination period is replaced when it is the lowest yielding candidate for voluntary culling and a heifer is ready to calf and thus, to enter the herd. The proportion of cows showing estrus after calving was set at 0.95. Replacement rate is determined as a result of individual cows' reproductive performance, disease occurrence, involuntary culling, mortality and the availability of replacement heifers. Involuntary culling is determined based on a base-risk of 0.9% in week 1 that declines linearly to a risk of 0.079% in week 29. The weekly risk remains constant at 0.079% for the remainder of the lactation period. Mortality is based on a constant, weekly base-risk of 0.034%. In addition to the base risks of involuntary culling and mortality, production diseases like mastitis (Østergaard et al. 2005b), metabolic diseases (Østergaard et al. 2000) and diseases that may result in lameness (Ettema et al. 2010) as simulated in SimHerd may increase a cow’s individual risk of involuntary culling and mortality. All parameters describing the lactation curve model in SimHerd are identical to those described by Kristensen et al. (2008).

The conception rate of heifers is set at 0.55, and visual estrus detection rate is assumed to be 0.55. An additional risk of fetal death, which includes early fetal death, is set at 0.13. These assumptions result in conception in 90% of all heifers during the artificial insemination period. Heifers that do not conceive during this period are sold to slaughter. Heifers are sold as livestock when no cows are selected for culling and a maximum number of cows is reached. Additional heifers are purchased when herd size falls below a minimum number.

3 Results

The profitability of automatic heat detection systems is determined by necessary investment costs and additional transaction costs. Annual costs for Heatime® Pro (figure 1) are composed of expenses for acquisition of sensors and basic additional equipment (antenna, transformer, wire, software) and implementation and repair costs. Increasing herd size leads to a cost degression caused by the distribution of fixed costs across a larger number of cows, especially for basic equipment. When more than 45 Sensors are purchased, annual costs of investment amount to less than 40 € per animal.

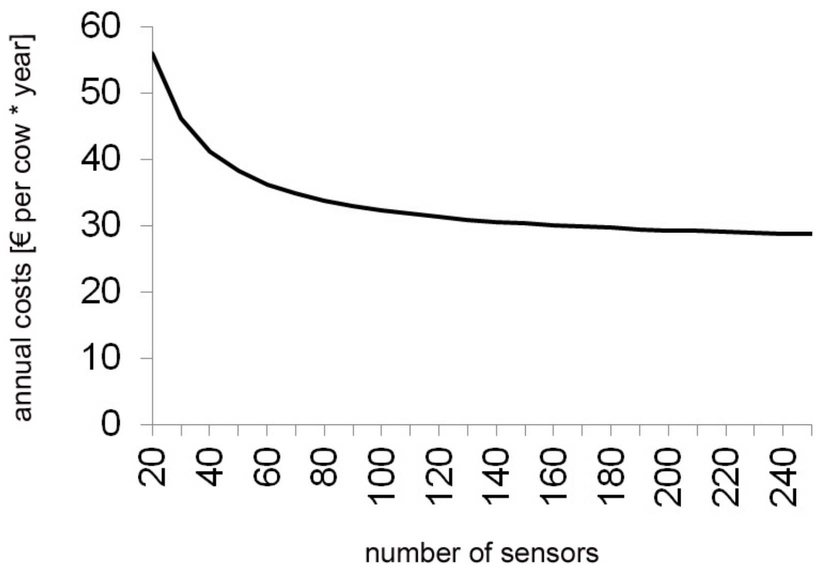

Fig 1. Annual costs of investment in automatic heat detection using the example of Heatime® Pro

Figure 2 shows the modeled GM (SimHerd) depending on heat detection rates of cows and heifers in two herds with average milk yield levels of 7000 and 9000 kg, respectively. An increase in GM with rising heat detection rates can be attributed to higher revenues obtained for calves. This results from shorter calving intervals, lower age at first calving and, therefore, a higher number of births per year in the herd (lower replacement costs). Depending on the strategy of a dairy farm, revenues from the sale of heifers or cows rise with increasing heat detection rates. Changes in milk yield are dependent on the balance between positive and negative effects. On the one hand, better reproductive performance leads to a shorter period of time that cows spend in late lactation, to more calves being born, and to a higher share of cows in peak yield per year. On the other hand, this also results in a higher share of dry cows, because cows reach the dry period faster when they reproduce, which has a negative effect on the average milk yield of the herd. Improved performance may also be connected with a higher average age of lactating cows (higher number of productive years per cow) and thus with increased susceptibility to disease.

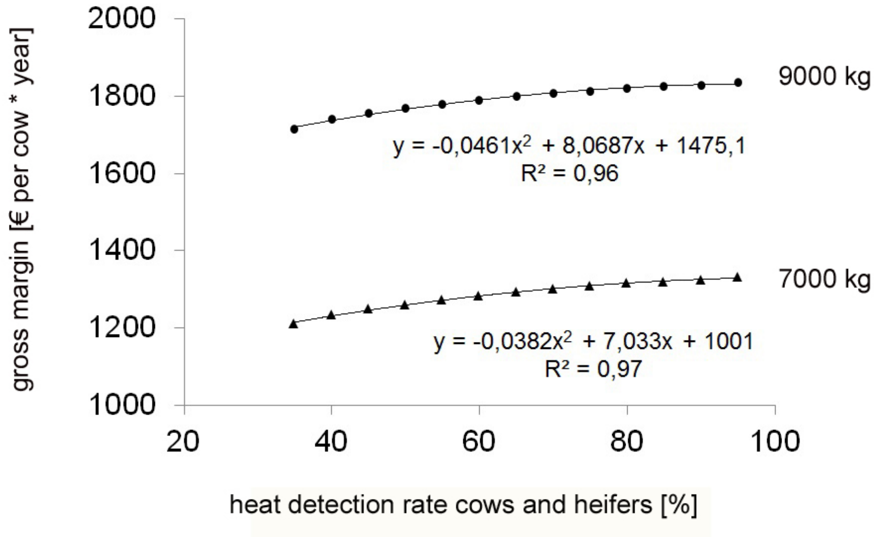

Fig 2. Gross margin per cow and year as a function of heat detection rate of cows and heifers

The integration of uncertainty in selected variables using @RISK results in probability distributions for the NR of investment in automated heat detection in each of the different scenarios analyzed. For each scenario, 1000 iterations reveal possible combinations of heat detection rates and time spent on heat control, including the probability of occurrence, based on the defined triangle distributions. Figure 3 shows an example of the probability distribution for the NR for a herd of 70 cows with a milk yield level of 9000 kg. Labor costs of 15 €/h are assumed in this scenario. The average NR are 12 € per cow and year (in the scenario where only cows are equipped with the automated heat detection system) and 28 € per cow and year (in the scenario where both cows and heifers are equipped). The probability of a positive NR is 79 % (only cows) and 91 % (cows and heifers), respectively. The level of NR is high for farms with a low visual heat detection rate and/or a high expenditure of time for heat control. In contrast, dairy farms which have a high visual heat detection rate and/or spend little time for heat control tend to have low or even negative NR.

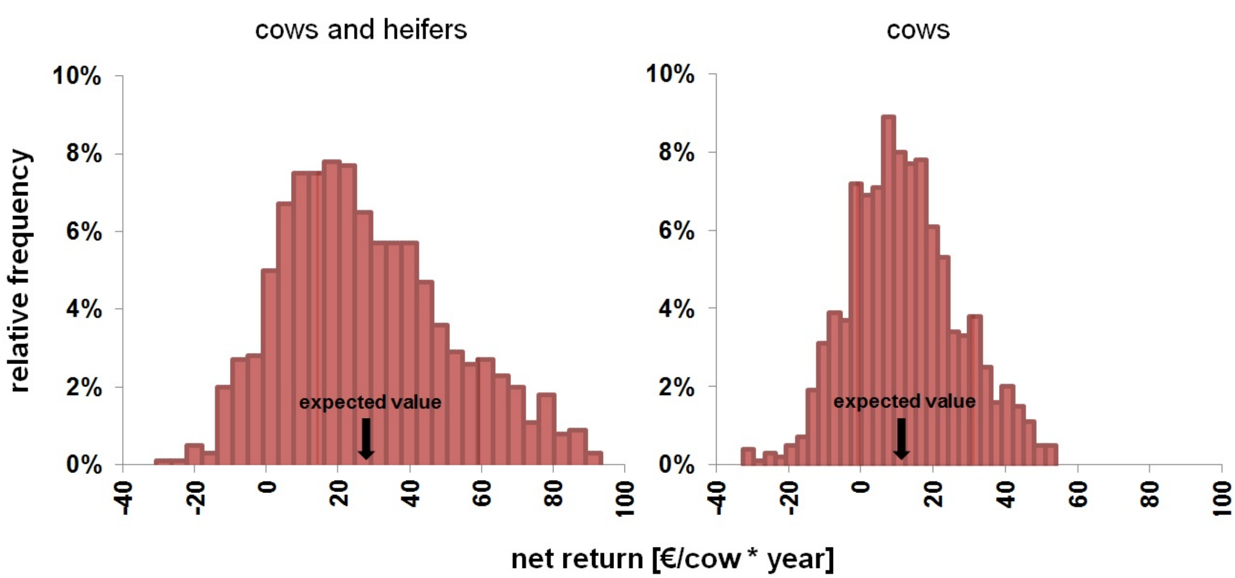

Fig 3. Net return distribution of the investment in automated heat detection for milk yield level of 9000 kg and herd size of 70 cows (1000 iterations)

The simulation results show that the NR with the automatic heat detection system ranges from -33 to +111 € per cow and year, with mean values of +6 to +35 € per cow and year (see table 2). The NR is independent of the assumed milk yield level. A comparison of all scenarios shows higher NR for bigger herd sizes, due to fixed cost degression effects. Equipping not only cows but also heifers leads to higher NR, and also to a higher probability of a positive NR. Net returns also tend to be higher when cost of labor is higher. Considering all the scenarios shown in table 2, the probability of a positive NR of an automatic heat detection system is, on average, 82 %.

Table 2. Net returns of the investment in automated heat detection of simulated scenarios (1000 iterations)

milk yield/year [kg]	**7000**				**9000**			
herd size [cows]	**70**		**210**		**70**		**210**	
equipping of …	**cows**	**cows + heifers**	**cows**	**cows + heifers**	**cows**	**cows + heifers**	**cows**	**cows + heifers**
minimum	-30*	-24	-24	-25	-30	-24	-18	-26
	*-33***	*-28*	*-15*	*-9*	*-33*	*-25*	*-14*	*-12*
mean	6	21	10	24	7	22	11	25
	17	*32*	*20*	*34*	*18*	*33*	*20*	*35*
maximum	52	92	60	98	55	99	63	111
	56	*90*	*60*	*98*	*60*	*101*	*65*	*109*
ratio [%] net return > 0 €/cow * year	61	80	69	79	60	77	67	79
	89	*95*	*94*	*97*	*87*	*95*	*92*	*96*

*labor cost is set to 10 € per hour; **numbers in italics indicate labor cost of 20 € per hour

4 Discussion

The simulation results reveal that the economic advantage or disadvantage of automatic heat detection technologies depends strongly on the dominant fertility management strategy of a dairy farm. However, investing in automatic heat detection systems results in a positive NR for the majority of dairy farms, independent of milk production level and herd size. It is recommended that not only cows but also heifers be equipped with heat detection devices, due to the importance of an optimal age at first calving, for which the economic benefits are already known (Ettema and Santos 2004). The results also confirm the relevance of a low calving interval, because costs of an unrecognized heat are estimated to be from 40 – 80 € (Jung 2009). It should also be taken into consideration that dairy farmers choose calving intervals individually for their farms, and that some of them lower them only to a certain level. Often, savings of time, greater attractiveness of work and, therefore, a higher level of convenience as a result of sensor-supported heat detection, are weighted higher than economic benefits. The results can be transferred to the majority of automatic heat detection systems available, whose heat detection rates are comparable to that of Heatime® Pro (e.g. Rutten 2013, Jónsson et al. 2011, Hockey et al. 2010). A survey (Michaelis et al. 2013) shows that 95 % of dairy farmers who have employed heat detection systems would install the system again (n = 219). Although only 54 % of the dairy farmers surveyed reported financial benefits from using Heatime, only 18 % stated the technology achieved no increase in financial profit. The remaining dairy farmers (25 %) experienced neither a positive nor a negative financial effect (Michaelis et al. 2013). These practical experiences coincide with the results of this study, as, on average, only 16 % of simulation runs showed negative net financial returns.

The effect of changes in the reproduction performance on milk yield is dependent on the shape of the lactation curve (Seegers 2006). It is already known that the impact of long calving intervals on productivity depends on the persistency of the lactation curve (Louca and Legates 1967; Olds et al., 1979). With deteriorating reproduction performance, reduction in milk yield is higher for lactation curves with low persistency and strong peaks than for flat curves with good persistency (Seegers 2006). The change in GM due to improving heat detection rate also depends on whether the same culling criteria are maintained. In SimHerd, a cow becomes a culling candidate as soon as she has exceeded a maximum number of days open. If this maximum number is maintained once heat detection rate is improved, the number of culled cows will be greatly reduced. If, on the other hand, the maximum number of days-open is reduced in combination with improving heat detection rate, the culling rate will remain unchanged. Whether maintaining or changing the culling criteria is profitable depends, in part, on the slaughter value of cows. Different culling criteria have not been included in this analysis, and would have introduced another dimension to this question.

The multiplicity and complexity of influencing factors makes it difficult to determine the economic impacts of automatic heat detection systems for which reason a stochastic model, as is applied in this study, is an appropriate approach to evaluating such effects.

5 Conclusion

Analyzed scenarios show positive annual NR for the majority of simulation runs (on average 82 %) when investing in automatic heat detection systems using the example of Heatime® Pro. The financial advantage or disadvantage depends strongly on the dominant reproduction management method of a dairy farm. A strong positive economic effect can be achieved with an additional equipping of heifers, which results in a lower age at first calving. Investing in heat detection technology also has the positive side effect of a more intense focus on the topic heat detection, which can also contribute to optimized reproduction management. Moreover, sensors for automatic heat detection are often equipped with additional functions for early detection of illnesses resulting in additional benefits.

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6 References

Diskin, M. G., & Sreenan, J. M. (2000). Expression and detection of oestrus in cattle. *Reproduction Nutrition Development,* 40, 481–491.

Ettema, J., & Santos, J. (2004). Impact of age at first calving on lactation, reproduction, health and income in first-parity holstein on commercial farms. *Journal of Dairy Science*, 87, 2730–2742.

Ettema, J. F., Østergaard, S., & Kristensen, A. R. (2010). Modelling the economic impact of three lameness causing diseases using herd and cow level evidence. *Preventive Veterinary Medicine,* 95, 64-73.

Ettema, J. F., Østergaard, S., & Sørensen, M. K. (2011). Effect of including milk yield on evaluating the use of sexed semen and other reproduction strategies in a dairy herd. *Animal,* 5, 1887-1897.

Firk, R., Stamer, E., Junge, W., & Krieter, J (2002). Automation of oestrus detection in dairy cows: a review. *Livestock Production Science*, 75, 219–232.

Gasteiner, J. (2014). Methoden der Brunsterkennung beim Rind. 6. Tierärztetagung, 9-12. http://docplayer.org/33908332-Methoden-der-brunsterkennung-beim-rind.html. Accessed 09 March 2018.

Hockey, C. D., Morton, J. M., Norman, S. T., & McGowan, M. R. (2010). Evaluation of a Neck Mounted 2-Hourly Activity Meter System for Detecting Cows About to Ovulate in Two Paddock-Based Australian Dairy Herds. *Reproduction in Domestic Animals*, 45, 107-117.

Holman, A., Thompson, J., Routly, J. E., Cameron, J., Jones, D. N., Grove-White, D., et al. (2011). Comparison of oestrus detection methods in dairy cattle. *Veterinary Record - English Edition*, 169 (2), 47.

Jónsson, R., Blanke, M., Poulsen, N. K., Caponetti, F., & Hosjsgaard, S. (2011). Oestrus detection in dairy cows from activity and lying data using on-line individual models. *Computers and Electronics in Agriculture*, 76, 6-15.

Jung, M. (2009). Brunstbeobachtung: Welche Möglichkeiten bieten technische Hilfsmittel? Milchrindtage Brandenburg (Germany).

Kristensen, E., Østergaard, S., Krogh, M. A., & Enevoldsen, C. (2008). Technical indicators of financial performance in the dairy herd. *Journal of Dairy Science*, 91, 620–631.

Louca, A., & Legates, J. E. (1967). Production losses in dairy cattle due to open days. *Journal of Dairy Science*, 51, 573–584.

Michaelis, I., Hasenpusch, E., & Heuwieser, W. (2013). Estrus detection in dairy cattle: Changes after the introduction of an automated activity monitoring system? *Tierärztliche Praxis Großtiere*, 41 (2), 159–165.

Mottram, T. (2016). Animal board invited review: Precision livestock farming for dairy cows with a focus on oestrus detection. *Animal*, 10 (10), 1575-1584.

Nielsen, H. M. (2004). Economic values for production and functional traits in dairy cattle breeding goals derived by stochastic simulation (Ph.D thesis). Copenhagen (Denmark): The Royal Veterinary and Agricultural University, Department of Snimal Science and Animal Health.

Olds, D., Cooper, T., & Thrift, A. (1979). Effects of days open on economic aspects of current lactation. *Journal of Dairy Science*, 62, 1167-1170.

Østergaard, S., Sørensen, J. T., & Kristensen, A. R. (2000). A stochastic model simulating the feeding-health-production complex in a dairy herd. *Journal of Dairy Sci*ence, 83, 721-733.

Østergaard, S., Chagunda, M. G. G., Friggens, N. C., Bennedsgaard, T. W., & Klaas, I. C. (2005a). A stochastic model simulating pathogen-specific mastitis control in a dairy herd. *Journal of Dairy Science*, 88, 4243-4257.

Østergaard, S., Friggens, N. C., & Chagunda, M. G. G. (2005b). Technical and economic effects of an inline progesterone indicator in a dairy herd estimated by stochastic simulation. *Theriogenology*, 64, 819-843.

Reith, S., Brandt, H., & Hoy, S. (2014). Simultaneous analysis of activity and rumination time, based on collar-mounted sensor technology, of dairy cows over the peri-estrus period. *Livestock Science*, 170, 219–227.

Roelofs, J. B., & Van Erp-van der Kooij, E. (2015). Estrus detection tools and their applicability in cattle: recent and perspectival situation. *Animal Reproduction*, 12 (3), 498–504.

Rutten, C. J., Velthuis, A. G. J., Steeneveld, W., & Hogeveen, H. (2013). Invited review: Sensors to support health management on dairy farms. *Journal of Dairy Science*, 96, 1928–1952.

Seegers, H. (2006). Economics of the Reproductive Performance of Dairy Herds. Proceedings of the 24th World Buiatrics Congress. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.507.3857&rep=rep1&type=pdf. Accessed 09 March 2018.

Silper, B. F., Polsky, L., Luu, J., Burnett, T. A., Rushen, J., De Passillé, A. M., et al. (2015). Automated and visual measurements of estrous behavior and their sources of variation in Holfstein heifers. II: Standing and lying patterns. *Theriogenology*, 84, 333–341.

Wangler, A., Meyer, A., Rehbock, F., & Sanftleben, P. (2005). Wie effizient ist die Aktivitätsmessung als ein Hilfsmittel in der Brunsterkennung bei Milchrindern? *Züchtungskunde,* 77 (2/3), 110–127.