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Estimating the net return of a remote calving alarm system in a dairy farm

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ABSTRACT

The aim of the study was to evaluate the net return of the implementation of a remote calving monitoring system for obstetrical and neonatal assistance on the herd economy in a dairy farm model. A total of 680 parturitions over a 7-yr period were evaluated. Age at first calving was restricted from 23 to 27 mo for primiparous cows to be included. Among groups of cows that were ready to calve in a 15-d interval, primiparous and multiparous were randomly assigned to the experimental group and monitored through a calving alarm system, whereas the others accounted for controls. Final parturition groups were as follows: control primiparous (CPP, n = 218), control multiparous (CM, n = 345), monitored primiparous (MPP, n = 56), and monitored multiparous (MM, n = 61). Monitored groups received prompt calving assistance and first neonatal care, whereas the presence of farm personnel was discontinuous for controls. A biological model was built considering significant differences in calf loss, early culling, milk production, and days open between groups. Then, a partial budget model was used to estimate costs and net return on a simulated herd of 100 lactating cows. Incidence of calf death was greater in control groups (11.06% and 10.73% in CPP and CM, respectively) compared with monitored cows (0.00% and 1.69% in MPP and MM, respectively). Multiparous cows with calf loss had increased relative risk (relative risk = 3.487) for early culling compared with multiparous counterparts with no neonatal loss. Daily milk production in the first 2 mo was 3.79 kg greater in multiparous cows with no dead calf, compared with their counterparts. A significant difference in median days open was found in MPP and CPP (118 and 148 d, respectively). In the final economic model, different simulations were analyzed. They were created assuming different prices or hypothesizing calving monitoring only in primiparous animals. The model estimated different, but always positive, net return. In conclusion, implementing a calving alarm system led to a net return from €37 to 90 per cow per year (€1 = US$1.15 at the time of the study). However, the device alone is not sufficient: it must be supported by qualified calving monitoring and assistance. Optimized personnel presence in the calving area at the right time leads to prompt calving and neonatal calf assistance and colostrum feeding within the first hours of life, thus reducing calf death and days open, and increasing milk production.
Key words: dairy cattle, remote calving alarm system, calf mortality, fertility, net return

INTRODUCTION

In the modern dairy industry, optimal herd management is fundamental to ensure high reproductive performance and subsequent production and net return (Britt, 1985; Cabrera, 2014). Parturition is a crucial event because anomalies in this process such as prolonged or difficult calving negatively affect welfare, survival, and performance of both the cow and the calf (Kovács et al., 2016). Dystocia rate varies across countries and farms; in the United States the incidence ranges from 28.6 to 51.2% and from 10.7 to 29.4% in primiparous and multiparous cows, respectively (Meyer et al., 2001; Lombard et al., 2007), whereas in Europe lower incidence is reported, ranging from 3 to 22% and from 2 to 13% in primiparous and multiparous cows, respectively (Mee, 2008). Independent of the incidence, dystocia is associated with increased risk of calf mortality and morbidity within 30 d of age. Dystocia also increases the likelihood of trauma on the birth canal, retention of fetal membranes, uterine disorders, and decreased milk yield (Sheldon et al., 2009; McHugh et al., 2012). Furthermore, dystocia is negatively associated with fertility and dam survival, with subsequent negative effect on farm incomes (Mee, 2008). Numerous studies have analyzed costs related to days open and low milk yield, which averaged $0.57 to $1.95 per day per cow and $0.12 per kg of milk loss, respectively (Hol-

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mann et al., 1984; Groenendaal et al., 2004; Huijps and Hogeveen, 2007; Inchaisri et al., 2010). More recently, estimated economic loss due to days open varied between \$5.12 and \$6 for every day open (Cabrera, 2014). Benefits of improved reproductive performance include more selective and therefore optimal culling strategy (Meadows et al., 2005).

Calf death is defined as death of a calf just before or within 48 h after parturition and its incidence is reported to average 7% in US dairy herds, with primiparous more affected (11%) than multiparous cows (5.7%; Meyer et al., 2000; Lombard et al., 2007). These authors also reported a positive association between dystocia and neonatal loss, due to metabolic effects of distress and compression of the calf within the birth canal. Calf loss negatively affects farm efficiency by reducing available replacement heifers and male calves for selling.

Because of strong cross-interactions between dystocia, calf death, animal welfare, and farm net return, farmers and stakeholders started only recently to perceive dystocia as a high priority concern (Martin-Collado et al., 2017).

Simple management interventions such as increased calving monitoring can significantly reduce the effect of dystocia on dairy farms, ensuring both the delivery of a live calf and smoothing the transition of the cow from dry to lactation period. Insufficient monitoring around the time of parturition might lead to prolonged labor, thereby increasing the risk of calf death (Gundelach et al., 2009). Furthermore, monitoring the delivery ensures timely colostrum administration within the first 6 h of life (Blum and Hammon, 2000), which is essential to improve the health and survival of neonatal calves (Quigley et al., 2001). Recently, a remote calving monitoring system was developed and implemented in field conditions in dairy farms (Palombi et al., 2013). Palombi et al. (2013) demonstrated that the remote alarm system used to monitor calving ensured the prompt presence of personnel, improving both the cow's reproductive efficiency and neonatal viability.

The aim of the present study was to evaluate whether the systematic implementation of a remote calving monitoring system, together with timely obstetrical and neonatal assistance, could be beneficial to the overall herd profitability in terms of reduced incidence of calf death, reduced risk of being culled during the first 2 mo of lactation, increased milk production, and better reproductive performance. Indeed, before implementation of the remote calving monitoring system in dairy farms, hypothetical net return should be evaluated. Economics provided herein could be useful to support the decision process.

MATERIALS AND METHODS

Animals and Husbandry

All animals involved in the study belonged to a dairy farm located in Umbria region (42°95′N, 12°39′E), in central Italy. The farm was officially free from brucellosis, tuberculosis, and bovine leukemia virus, infectious bovine rhinotracheitis, and bovine viral diarrhea virus. The herd was composed of Italian Holstein breed cows, for an average of 110 deliveries per year. Mean ± standard deviation of BCS at calving was 3.50 ± 0.23 for primiparous and 3.25 ± 0.48 for multiparous cows, respectively, on a 5-point scale (Edmonson et al., 1989).

Lactating cows were housed in 2 freestall barns with cubicles and automated milking system. Those included milking robots, for an average of 50 to 60 cows each group (VMS, DeLaval S.p.A., San Donato Milanese, Italy), with the same feeding management. Transition and calving areas consisted of 2 adjacent barns with straw bedding. Heifers and dry cows were moved to the transition pen 3 wk before the expected calving date. In all areas, animals had free access to feed bunk and water. A TMR was distributed twice a day, approximately between 0400 and 0500 h and between 1500 and 1600 h.

After calving, cows were monitored twice a week through a complete clinical and reproductive tract examination until complete uterine involution was assessed. A voluntary waiting period of 45 d was observed.

Experimental Design

A total of 680 parturitions over a 7-yr period were evaluated. Age at first calving was restricted from 23 to 27 mo for primiparous cows to be included. Exclusion criteria were represented by occurrence of abortions and premature parturition (n = 20) and crossbreeding (n = 40).

Among groups of cows that were ready to calve in a 15-d interval, primiparous and multiparous cows were randomly extracted through casual selection of their identification number. They were subsequently included into the experimental group and monitored through a calving alarm system, whereas the others were controls. If the selected animals did not calve in the range of 15 d, they were not included in the results.

Final parturition groups were as follows: control primiparous (**CPP**, n = 218), control multiparous (**CM**, n = 345), monitored primiparous (**MPP**, n = 56), and monitored multiparous (**MM**, n = 61).

Monitored groups received prompt calving assistance and first neonatal care. Control animals delivered in the calving area, but monitoring and assistance by farm personnel was discontinuous and depended on their proximity to the calving barn. Moreover, during the night hours, that is from 1800 to 0400 h, personnel were absent. In case of difficult parturition, workers provided calving assistance or called for veterinary intervention when severe dystocia occurred. Otherwise, control cows calved unassisted. Thus, degree of dystocia was not recorded in control animals; however, calf death was assumed to represent an indirect but reliable estimation of calving difficulty.

Prepartum Evaluation and Application of the Intravaginal GSM Device

A clinical evaluation of the degree of relaxation of pelvic ligaments together with the assessment of loosened cervical mucus plug were performed. Once those premonitory signs of calving were detected, that is 3 ± 1 d before expected delivery, the alarm device was applied. Cleansing and scrub of the perineum and vulva were performed with diluted iodine solution (7.5% Povidone-Iodine solution, Betadin Meda Pharma S.p.A., Milano, Italy); then, the device was inserted through gloved hand into the vagina until contact with external cervical os.

The calving alarm system (patent number: 0001405187–12/20/2013–WIPO: 10UD2011A000062) consisted of a control unit and an intravaginal device, as previously described (Palombi et al., 2013). Briefly, the device for the detection of delivery was characterized by a probe composed of a base and a cylindrical bin. The base consisted of an anchoring system that secured the device to the vaginal wall, and the bin contained physical sensors and the transmitter. Once expelled from the vagina, at the beginning of stage 2 of labor, the transmitter sent a radio signal decoded by a receiving station that activated the GSM autodialer within the control unit, which in turn sent an SMS and a phone call alert to user contacts previously recorded in the control unit memory.

Obstetrical and Neonatal Assistance

In monitored animals, once the alert from the control unit was received, the operators reached the calving area in 21 ± 4 min, ensuring obstetrical evaluation to assess fetal presentation, position, and posture, together with the degree of cervical dilation. Dystocia management was carried out according to recognized obstetrical procedures (Richter and Götze, 1978). Colostrum of good quality, that is with IgG content >50 g/L and score >22% on a Brix scale (Buczinski and Vandeweerd, 2016), was administered within the first 2 h of life in calves born from monitored animals.

All newborn calves from the control group received colostrum by the farm workers, but the timing of colostrum administration widely varied across animals depending on workers' presence in the barn.

Data Collection

Average daily milk yield was recorded for each cow between 7 and 30 DIM for the first test-day, and between 31 and 60 DIM for the second one.

Day of calving, calf sex, calf death, twinning, days open, and culling occurrence were retrieved from the Farm Software (Si@lleva, Associazione Italiana Allevatori, Rome, Italy).

The experimental activity was carried out in accordance with the guidelines on use of animals for experimentation set by the Italian Decree Law 116/92 and has been approved by the Ethical Committee of Perugia University on 14/06/2012, protocol no. 2012–025.

Statistical Analysis

Single parturition was considered as the experimental unit. Initially, the data set was analyzed using SAS software v9.4 (SAS Institute Inc., Cary, NC) to evaluate the association between use of the calving alarm system and calf death, days from calving to conception, milk production, and early culling rate during the first 60 d of lactation. Associations were considered statistically significant when P-value was <0.05.

We hypothesized that using a calving alarm system could influence both directly and indirectly fertility, early culling, and milk production, through appropriate calving assistance and reduction of negative effects of prolonged labor and dystocia. Because calf death could be considered an indirect measure of calving difficulty, the statistical model was also corrected, where applicable, for fixed effect of calf death (Meyer et al., 2000; Mee, 2004; Lombard et al., 2007).

The association between the outcomes calf death, early culling, and the following variables were considered: use of the calving alarm system, year of calving, and month of calving. Associations were tested separately in primiparous and multiparous cows using 2 × 2 tables and a χ^2 test with 1 degree of freedom (PROC FREQ). No association was found with year of calving and month of calving, and therefore baseline risks and relative risk for calf death and early culling associated with use of the calving alarm system were derived from the 2 × 2 tables.

Linear models with a marginal effect (PROC MIXED) were used to estimate milk production in primiparous (MPP vs. CPP) and multiparous cows (MM vs. CM), respectively, based on milk production from the first 2 test-days. The general form of the model was

$$Y = \text{MIM (2 index variables)} + \text{TRT (2 index variables)} + \varepsilon,$$

where Y was test-day milk production, MIM was month in milk, TRT was treatment group, and ε was a complex error term representing the within-cow correlation of test-day results and the residual error. The covariance structure chosen for the **R** (error) matrix was autoregressive, i.e., $\left(\sigma^2\rho^{|i-j|}\right)$, where σ^2 = variance, ρ = autocorrelation coefficient, and i and j = 2 elements of the repeated measurements.

Days from calving to conception in primiparous (MPP vs. CPP) and multiparous cows (MM vs. CM) were analyzed using the Kaplan-Meier method (PROC LIFETEST), and median days to conception for the treatment groups within parity groups were obtained.

Model Inputs for Partial Budget

A partial budget model as described by McArt et al. (2015) was applied to calculate costs and net return deriving from the implementation of a calving alarm system in a dairy farm.

Because costs associated with feeding, housing, veterinary, and farm workload for routine farm operations, together with other disposable materials, were considered the same between experimental and control groups, they were not considered in the partial budgeting model. Time needed for insertion of the intravaginal device consisted of few minutes; therefore, the cost consisted of one disposable rectal palpation glove, warm water, a few milliliters of iodine solution, and a few milliliters of lubricant gel. Those costs were then considered as negligible. Concerning feeding, only costs due to extra milk production in experimental animals, as discussed below, were considered.

Average market prices were calculated based on reports published by the Italian Institution for Agro–Food Market Services (ISMEA, 2019), unless differently specified. Raw milk price was set as €0.42/kg, assuming no seasonal price variations during the period of the study (€1 = US$1.15 at the time of the study). Replacement costs were set considering the cost for a ready-to-calve heifer or cow, which accounted for €1,800 and €2,200, respectively, as shown for north-central Italy. To calculate losses due to calf death, prices for 10-d calves were set as €350 and €90 for females and males, respectively, assuming that male calves would be sold for meat production, whereas females would be grown for future replacement. Losses due to days open were set as €5 for every day open (Cabrera, 2014).

To calculate costs associated with extra feed consumption in experimental groups due to increased milk production, average daily milk yield was set as 33.23 kg/d in a standard 305-d lactation, as reported by the National Association of Italian Friesian Breeders (ANAFI, 2018). For each lactating cow, it was considered a daily DMI of 23.5 kg, for an average daily price of €0.28 per kg TMR (data retrieved from the farm software). Then, feed/milk ratio was calculated as DMI/daily milk yield, estimated to be 0.707. This ratio was used to estimate feeding costs due to increased milk production as follows:

$$\text{cost of 1 kg extra milk yield} = \text{1 kg TMR price} \times \text{feed/milk ratio} \times \text{kg extra milk yield}.$$

Costs related to the calving alarm system were represented by the purchase of one control unit (€2,000), assuming amortization in a 5-yr interval, together with intravaginal devices (€65/device), with each device calculated to work for 30 deliveries (€2.17/delivery).

Prices and other inputs used to build the economic model are summarized in Table 1.

Partial Budget Development

Using estimates from this initial analysis, a partial budget model was built using Excel (Microsoft Office,

Table 1. Model inputs used to evaluate costs and net return from implementation of a calving alarm system in our experimental dairy herd (€1 = US$1.15 at the time of the study)

Input variable	Measure or price
Herd characteristic	
Lactating cows (no.)	100
Primiparous/multiparous ratio	0.35
Cost or price	
Milk price (€)	0.42[1]
1 kg of DM of lactation TMR (€)	0.28
Alarm system, control unit (€)	2,000
Control unit amortization (yr)	5
Alarm system, device (€)	65
Device/delivery (€)	2.17
Calf price, female (€)	350[1]
Calf price, male (€)	90[1]
Replacement heifer[2] (€)	2,200[1]
Replacement cow[2] (€)	1,800[1]
Days open (d)	5[3]

[1]ISMEA (Italian Institution for Agro–Food Market Services), 2019.

[2]Replacement heifer or cow: account for total costs for purchase of a ready-to-calve heifer or cow, respectively.

[3]Cabrera (2014).

Table 2. Number of events with prevalence (%) in parentheses of early culling and calf death in the experimental and control group[1,2]

Item	MPP (n = 56)	CPP (n = 218)	*P*-value	MM (n = 61)	CM (n = 345)	*P*-value
Early culling	1 (1.79)	13 (5.96)	0.172	4 (6.56)	41 (11.88)	0.273
Calf death	0 (0.00)	24 (11.01)	0.008	1 (1.64)	37 (10.72)	0.028
Milk production (kg/d)	+0.65 ± 8.86	27.12 ± 1.19	0.422	+0.09 ± 1.13	39.99 ± 2.67	0.937
Days open (d)	118	148	0.004	128	163	0.263

[1]Mean ± SE of daily milk yield, expressed as estimated mean in CPP and CM, and as difference in MPP and MM, respectively. Median days open in experimental and control groups.

[2]MPP = monitored primiparous; CPP = control primiparous; MM = monitored multiparous; CM = control multiparous; early culling = culling within 60 d of lactation. Mean milk production and differences: estimated intercept from mixed model adjusted for parity, group, test-day, and year of calving. Mean days open: Kaplan-Meier analysis. *P*-value for early culling and calf death: Two-sided χ^2 test. *P*-value for milk production: *F*-test; *P*-value for days open: Wilcoxon test.

Microsoft Corporation, Redmond, WA). This model was then used to evaluate the net return of using the calving alarm system on a herd of 100 lactating cows, composed by 35% primiparous and 65% multiparous animals. Only variables that demonstrated a significant effect in the initial biological analysis were included in the partial budget.

The general formula used to calculate the amount of events prevented by the alarm system, such as calf death and early culling, was as follows:

$$N_{prevented} = N_{exposed} \times \text{incidence} \times (1 - RR),$$

where $N_{prevented}$ was the number of prevented cases, $N_{exposed}$ was the number of animals exposed to risk factors relative to the event itself, and RR was the relative risk for the event.

The number of prevented cases was then multiplied for the associated cost as follows:

$$€_{saved} = N_{prevented} \times \text{cost},$$

where $€_{saved}$ was the net return for the farm due to prevention of economic losses, $N_{prevented}$ was retrieved from the previous formula, and the cost was extrapolated from Table 1.

RESULTS

The data set included 680 deliveries and relative lactations, with overall parity ranging from 1 to 8. Only one cesarean section due to uterine torsion has been required during the period of study, with extraction of a dead male calf in the CM group. A total of 62 dead calves were recorded, for an overall herd prevalence of 9.13% during the study period, whereas twinning accounted for 4.7% of all pregnancies. During the first 60 DIM, 8.6% of all observed cows were culled, independent of parity or group.

In Table 2 are summarized calf death and early culling events, mean milk production and median days open, in experimental and control animals. In Table 3, the effect of calf death on the prevalence of early culling, mean milk production in the first 60 d of lactation and median days open in primiparous and pluriparous cows, is shown. In Table 4, incidence of calf death and early culling with confidence interval and relative risk in experimental and control groups are reported.

Calf death events were greater in percentage of control animals (11.06% and 10.73% in CPP and CM, respectively) than in monitored ones (0.00% and 1.69% in MPP and MM, respectively) with significant differences between both primiparous (P = 0.001) and

Table 3. Effect of calf death on the incidence of early culling, mean daily milk production, and median days open in primiparous and pluriparous cows[1,2]

	Primiparous (n = 274)			Multiparous (n = 406)		
Item	No calf death (n = 250)	Calf death (n = 24)	*P*-value	No calf death (n = 368)	Calf death (n = 38)	*P*-value
Early culling (%)	11 (4.40%)	3 (12.50%)	0.109	33 (8.97%)	12 (31.58%)	<0.001
Milk production (kg/d)	27.72 ± 1.12	−2.22 ± 1.29	0.087	41.01 ± 2.66	−3.79 ± 1.37	0.006
Days open (d)	134	103	0.004	159	224	0.070

[1]Mean ± SE of daily milk yield is expressed as estimated mean in cows without calf death, and as difference in cows with calf death, respectively.

[2]Early culling: culling within 60 d of lactation. Mean milk production and differences: estimated mixed model adjusted for parity, group, test-day, and year of calving. Mean days open: Kaplan-Meier analysis. *P*-value for early culling: Two-sided χ^2 test. *P*-value for milk production: *F*-test; *P*-value for days open: Wilcoxon test.

Table 4. Incidence and relative risk of calf death and early culling in experimental and control groups[1]

Item	MPP vs. CPP			MM vs. CM		
	Incidence	95% Exact confidence limits	Relative risk	Incidence	95% Exact confidence limits	Relative risk
Direct (calving alarm system)						
Calf death (%)	0.111	0.071–0.161	0.158	0.107	0.077–0.144	0.158
Indirect (through reduced calf death)						
Early culling (%)	0.347	0.104–1.156[NS]	2.88	0.287	0.162–0.508	3.487

[1]MPP = monitored primiparous; CPP = control primiparous; MM = monitored multiparous; CM = control multiparous; early culling: culling within 60 DIM; NS: nonsignificant, not included in partial budget model.

multiparous cows ($P = 0.028$). Similar trend could be found also concerning early culling, even if differences were not significant.

Accounting for the fixed effect of reduced calf loss, primiparous cows showed a nonsignificant difference in early culling. In multiparous, a significant increase ($P < 0.001$) in risk of early culling was identified in those cows with neonatal loss (relative risk = 3.487) and this risk was subsequently considered in the final economic model.

Mixed linear model for milk production showed that during the first 2 mo of lactation, there was no difference between monitored and control groups. When correcting for calf death event as covariate, primiparous cows with no calf death produced on average 2.22 kg of milk per day more than lactations associated with calf loss. However, since $P = 0.087$, this effect was not included in the partial budget model. In multiparous groups, production difference was significant ($P = 0.006$) and cows without calf loss produced on average 3.79 kg milk per day more when compared with the counterparts. This increase in milk yield was then included in the final partial budget, taking into consideration extra feed consumption for milk production as an added cost.

Survival analysis revealed, as a direct effect of the calving alarm system, a significant difference ($P = 0.004$) in median days to conception in MPP and CPP, namely 118 and 148 d, respectively. Concerning MM and CM, differences were not significant and the median interval from calving to conception was 128 and 163 d, respectively ($P = 0.263$). Assuming calf death as a covariate, analyzing indirect effect of using calving alarm system, primiparous cows with no associated calf loss showed median interval from calving to conception of 134 d, whereas animals that underwent calf death event had a median interval of 103 d ($P = 0.004$). This indirect effect was then included in the final partial budget model, after correction for relative risk of calf death in monitored groups. Concerning multiparous cows, accounting for the fixed effect of calf death into the survival analysis, animals with a live calf had median interval to conception of 159 d, whereas cows with associated calf death showed a median interval of 234 d. However, the difference was not significant, and thus this effect was not included into the final partial budget model.

The final partial budget model is summarized in Table 5. Compared with a control herd, a 100-lactating cows farm that implemented a calving alarm system in all parturient animals was able to increase the net return by €9,070 per year. One of the major sources of income was derived from reduced calf death and loss of weaned animals that could be sold for meat production (male calves) or used as future replacement. Another substantial component of net return was represented by the reduction in days open, which accounted for €4,743. Different simulations, through variation of market price for calves, replacements, cost of a single day open, or hypothesizing implementation of a calving alarm system only in primiparous animals, led to a different net return. The smaller one belonged to simulation 4, where major sources were minimized: costs of days open were assumed as €0.57 per day, prices for 10-d calves were fixed at €200 and €50 for females and males, respectively, whereas replacement heifers and cows prices were fixed at €2,000 and €1,500, respectively. This scenario led to final net return of €3,699 per 100 lactating cows per year.

DISCUSSION

The present work investigated main economic pros and cons of using a remote calving alarm system in a dairy farm through a partial budget model, considering the effect of the device on calf death incidence, risk of being culled in the first 60 DIM, milk production, and reproductive outcome.

Phenotypic trend for calf death and dystocia prevalence is increasing in the Holstein breed (Meyer et al., 2001; Mee, 2013), and at present, most deliveries in intensive dairy farms are unassisted, thus increasing the risk of prolonged labor with negative consequences both on the mother and the calf. In the present study, based on a 7-yr farm database, exact dystocia prevalence could not be ascertained because the majority of parturitions in control groups were unassisted. Farm workers could assist calving, depending on their presence in the proximity of the calving barn and on the visual recognition of the delivery. Thus, some calvings in the control group were completely unmonitored and unassisted. In some cases assistance was provided, but probably late relative to the exact progression from stage I to stage II of labor. The variability of those events made statistical comparison impossible. Calf death incidence, however, is positively correlated with calving difficulty, which is why in our work, we used this information as an indirect measure of dystocia (Mee, 2013). Overall farm prevalence of calf death was 9.13%, which is in accordance to what is reported worldwide (Meyer et al., 2001; Lombard et al., 2007; Mainau and Manteca, 2011). Also for twin pregnancies, our observations were within ranges described by other authors (Andreu-Vázquez et al., 2012; Szelényi et al., 2019). Control groups showed greater calf loss than monitored ones. Because the calving alarm system used in this study was able to identify the beginning of stage 2 of labor, prompt monitoring and assistance were provided as soon as the limbs of the fetus entered the birth canal and the fetal sacs ruptured. This led to quick recognition of calving difficulties and reduced the risk of neonatal distress, hypoxia, and metabolic acidosis. These conditions are generally linked to reduced calf vitality and colostrum intake, failure of passive transfer immunity, and increased calf death within the first week of life (Mainau and Manteca, 2011). Moreover, once received the calving alarm, 2 L of frozen/thawed good-quality colostrum was administered to the neonate within 2 h of life. On the contrary, calves from the control group received colostrum by farm workers, depending on the time of birth. More in detail, if a calf was born during night hours, no farm workers were present and colostrum administration was postponed to the following day, usually after unifeed distribution. That means that calves born during the night received colostrum at least after 0730 h, thus making impossible to estimate the exact interval between birth and first feeding. In case a calf was born during work hours, the time of colostrum feeding varied again, based on the presence of workers in the barn; even if workers could assist with parturition, calf separation, mother milking, and colostrum administration could be postponed for various hours after delivery, depending on workload.

It is interesting to note that the percentage of postpartum cows culled within 60 DIM was greater for CPP

Table 5. Partial budget model in a herd of 100 lactating cows in which a calving alarm system is systematically implemented in all parturient animals, compared with a control herd[1]

	Simulation[2]				
Effect of calving alarm system	1	2	3	4	5
Number of cows in 1 yr	100				
Primiparous (no.)	35				
Multiparous (no.)	65				
Direct effects					
Reduced calf death (per 100 cows)					
Primiparous (no.)	3.27				
Multiparous (no.)	5.86				0
Reduced days open primiparous (d)	1,050				
Indirect through reduced calf death (per 100 cows)					
Reduced early culling in cows (no.)	1.282				0.612
Milk in 60 d in cows (kg)	1,331.70				0
Reduced days open in primiparous, indirect (d)	−101.41				
Monetary units					
Replacement saved (€)	2,640.20			670.80	1,260.80
Dead calves (€)	2,008.00			1,140.90	2,249.80
Milk (€)	559.30				0
Extra feed cost for production (€)	−263.60			−263.60	0
Days open (€)	4,743.00	1,849.80	540.70	540.70	4,743.00
Cost for central unit (1 yr; €)	−400.00				
Cost for device (all cows; €)	−216.70				−76.00
Total (€)	9,070.20	6,177.00	4,867.90	3,699.6	7,777.50

[1]Only effects that were statistically significant in the biological model were considered in the economic evaluation. In simulations other than 1, only parameters that differed were entered.

[2]Simulation 1: represents the experimental herd involved in this study. Simulation 2: costs of days open were assumed as €1.95 per day. Simulation 3: costs of days open were assumed as €0.57 per day. Simulation 4: costs of days open were assumed as €0.57 per day; prices for 10 d calves were fixed at €200 and €50 for females and males, respectively; replacement heifers and cows prices were fixed at €2,000 and €1,500, respectively. Simulation 5: as in simulation 1, but hypothesizing implementation of a calving alarm system only in primiparous cows. €1 = US$1.15 at the time of the study.

and CM groups, even though this difference was not significant, when the effect of the calving alarm was analyzed directly. When corrected for calf death event, multiparous cows with no calf loss had less probability to be culled than counterparts. Investigation concerning reasons for culling was beyond the aim of the study; however, incidence of culling for lameness, mastitis, and low production in the first 60 DIM can be considered the same between experimental and control groups. As a consequence, the difference observed could be attributed to the effect of calving assistance and reduced calf death in monitored animals. Although pain associated with prolonged calving is frequently neglected, it represents an issue for dam welfare and could lead to reduced feed intake, loss in milk production, greater susceptibility to postpartum disease, and increased risk of being culled (Mee, 2008; Mainau and Manteca, 2011). It is possible that in our study, the group of monitored cows that had no or reduced incidence of calf death received proper calving assistance, thus shortening labor, reducing uterine contamination and pain, and decreasing the risk of postpartum diseases. Independent of this, the significant reduction in early culling in multiparous cows, when correcting the analysis for calf death events, is biologically justified by the fact that a calving alarm system alone is not responsible for improved health; the device must be supported by qualified monitoring and assistance during parturition.

A significant effect of the calving alarm system on milk production was evident in multiparous cows, but only after accounting for calf death incidence; cows with no calf loss produced on average 3.79 kg of milk per day more than control ones, in the first 60 DIM. Wittrock et al. (2011) observed a difference of about 4 kg of milk/d between healthy and metritic multiparous cows in the first 3 wk of lactation. Wittrock et al. (2011) also considered long-term effect of metritis on milk yield and reported that decreased production was noticeable up to 20 wk postpartum in multiparous animals, whereas primiparous cows showed no difference. As healthy cows showed greater feed intake and efficiency for milk production, we also hypothesized that in our study the utilization of a calving alarm system led to proper assistance during delivery and reduced distress for periparturient cows.

Concerning reproductive outcome, monitored groups had a median calving to conception interval one month shorter than control ones, even if this difference was significant only in primiparous cows, thus being considered in the partial budget. The decrease in days open in monitored primiparous cows could be due to proper calving assistance. Delivery in primiparous animals is usually longer in duration than multiparous cows, due to both greater interval for birth canal structures to relax and to pelvis dimension relative to fetus size. Prolonged parturition is generally associated with increased uterine contamination, risk of metritis, and delayed postpartum uterine involution. Proper calving assistance probably leads to quicker recovery of uterine environment and to greater conception rate in experimental animals. Once calf death event was accounted for in survival analysis, multiparous animals with no calf loss showed better performance, whereas primiparous with no calf death had longer calving to conception interval (134 d) compared with counterparts (103 d). This result should be considered with caution due to the small number of primiparous animals that lost a calf.

In the final partial budget model, net return deriving from systematic implementation of a calving alarm system was calculated for a herd of 100 lactating cows, with a typical composition of 35% primiparous and 65% multiparous cows. Since market prices for calves, replacements, and days open are variable, best and worst scenarios were simulated. Major components of net return were represented by calves sold and decreased days open, except for simulation 3 and 4, in which lowest costs for days open were assumed. Independent of the scenario, final partial budget was positive and demonstrated that optimized personnel attention to parturition, calving assistance, and first neonatal care could be effective in improving farm economy, leading to an average net return from €37 to €90 per cow per year. However, because some of the positive effect of a calving alarm system on farm net return is due to reduction in stillbirth, farm baseline incidence of difficult parturition and calf loss consistently influences the result.

We decided to exclude personnel and veterinary costs in our partial budget because our aim was to provide economic estimations with the widest external validity. Market prices are variable, but they apply objectively to various farms, whereas workers and veterinarian fees could be different on a single farm basis. We considered that practitioners were not to be called on farm for every calving alarm, but only in the case of severe dystocia. Moreover, McGuirk et al. (2007) evaluated how different factors induced losses in case of slightly or severely difficult calving in UK dairy herds, including veterinary costs for calving assistance. McGuirk et al. (2007) reported that veterinarian fees represented a minor cost, whereas calf death and reduced fat and protein yield in association with decreased fertility were the main factors that influenced the net return. In addition, the function of a calving alarm system is not to decrease the incidence of dystocia and therefore the associated assistance or veterinary costs, but to allow rapid recognition and to prevent the adverse effects of prolonged dystocia. Great variability exists concerning the employment contract between the farm and the personnel, night hours workload, and veterinary assistance. By excluding those costs from the partial budget, every farm manager will freely evaluate the cost of implementation of a remote calving alarm system on the farm, thus establishing whether the system could be advantageous on that single farm.

In this study, to maximize external validity for different farms, use of sexed semen for primiparous insemination and greater values for calves born from embryo transfer were not taken into account. This is likely to cause underestimation of total incomes together with those deriving from limiting calf death in primiparous animals. We considered costs associated with clinical obstetrical evaluation and intravaginal device application in prepartum cows as negligible. Economics hereby presented could be used by the farm manager to estimate the net return of improving a systematic calving alarm system at the farm level. However, as already suggested by the biological model, the device alone is not able to improve farm outcomes; the workload and the importance of personnel presence in calving area is not to be erased. Despite being important for quick intervention in case of prolonged parturition and dystocia, estimating the exact beginning of stage 2 of labor is challenging (Mee, 2004). Moreover, the continuous presence of personnel for the evaluation of expulsive phase of parturition could be a source of disturbance for parturient animals, thus inducing the release of catecholamines and interfering with the calving process (Mee, 2008). This phenomenon could be responsible for increased risk of calf death and dystocia, and reduced animal welfare. In a modern farm model, the implementation of a calving alarm system could concentrate personnel presence at the exact delivery time.

Disease prevention, calf survival, and delivery-related pain are components of animal welfare both from a biological and from a functional point of view (Sumner et al., 2018). A calving alarm system leads farmers and veterinarians to quickly intervene during delivery, thus reducing pain associated with prolonged parturition, improving calf viability and survival, ensuring administration of good-quality and pathogen-free colostrum and reducing the incidence of postpartum uterine disease. Moreover, calving and colostrum management together with early separation of the calf from the mother have been identified as some of the practices that could be helpful in reducing the incidence of paratuberculosis in the herd (Donat et al., 2016).

This improvement in animal welfare inevitably leads to reduced drug administration, milk withdrawal and involuntary culling, to greater fertility and, finally, net return. Because a calving alarm system is able to detect the beginning of the expulsive phase, an adequate time of intervention could be established in the decision process on when and how to intervene.

CONCLUSIONS

In conclusion, partial budget estimations for a systematic implementation of a calving alarm system in a dairy farm model showed an improvement in farm performance, leading to a net return from €37 to €90 per cow per year. The device alone cannot exert effects; it must be supported by qualified calving monitoring by farm workers. The optimization of the presence of personnel in the calving area at the right time can lead to prompt calving and neonatal calf assistance, and colostrum feeding within the first hours of life, thus reducing calf death and days open, and increasing milk production.

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