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Modelling the economic impact of three lameness causing diseases using herd and cow level evidence

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Abstract
Diseases to the cow's hoof, interdigital skin and legs are highly prevalent and of large economic impact in modern dairy farming. In order to support farmer's decisions on preventing and treating lameness and its underlying causes, decision support models can be used to predict the economic profitability of such actions. An existing approach of modelling lameness as one health disorder in a dynamic, stochastic and mechanistic simulation model has been improved in two ways. First of all, three underlying diseases causing lameness were modelled. This resulted in an estimated economic impact of €31, €67 and €261 per case of lameness caused by digital dermatitis, interdigital hyperplasia and hoof horn diseases, respectively. The estimates differed for herds with different levels of diseases risk and reproductive efficiency. Secondly, the existing simulation model was set-up in way that it uses hyper-distributions describing diseases risk of the three lameness causing diseases. By combining information on herd-level risk factors with prevalence of lameness or prevalence of underlying diseases among cows, marginal posterior probability distributions for disease prevalence in the specific herd are created in a Bayesian network. After transforming three parity specific disease prevalences into parity and lactation stage specific risks of disease occurrence by calibration, random draws from the distributions are used by the simulation model to describe disease occurrence in a herd. Hereby uncertainty around herd specific risk is represented and field data on prevalence is used systematically.

Key words: Lameness; dairy cattle; stochastic simulation; hyper distributions
1. Introduction

Disorders to the dairy cows’ hoofs, (inter) digital skin and legs are highly prevalent in modern dairy farming (Somers et al., 2003; Sogstad et al., 2005; Holzhauer et al., 2006; Capion et al., 2008). In case these hoof and leg disorders result in an altered locomotion, we often refer to the disorders’ clinical symptom, i.e. lameness. It is especially this symptom of the disorders that has been associated with reduced productive and reproductive performance (Collick et al., 1989; Barkema et al., 1994; Green et al., 2002). Reported incidences of clinical lameness vary from 21% per lactation (Enting et al., 1997) up to 70% in a 1.5 year study period (Green et al., 2002). The detrimental effects of lameness on productivity along with its high incidence make dairy cattle lameness of large economic importance. Enting et al. (1997) estimated an economic loss of €104 per case of clinical lameness. In an earlier simulation study Ettema and Østergaard (2006) estimated the costs per case of clinical lameness per cow-year on €192 in a typical Danish dairy herd; this estimate went up to €278 in case the modelled herd had low reproductive performance. Both studies focussed on lameness as one health disorder caused by a variety of claw, skin and leg disorders. Kossaibati and Esslemont (1997) clearly demonstrated the importance of considering different underlying causes of lameness in a partial budget analysis. Their estimated costs of a case of lameness per lactation were €343, €186 and €602 in case the cause was a digital disease, interdigital disease and a sole ulcer, respectively. In order to combine the abilities of a mechanistic simulation model with the approach of considering lameness’ underlying causes, the first objective of this study is to analyze the economic impact of three lameness causing diseases by simulation modelling.

The second objective of this study concerns the simulation model’s input parameters. The complete set of these parameters, i.e. the state of nature, of a livestock model are never known with certainty. In the earlier mentioned study with the Monte Carlo simulation model Simherd IV (Ettema and Østergaard, 2006), cow specific
probabilities for becoming diseased were calculated with a logistic regression model.
Variability between animals was represented since disease occurrence was triggered
stochastically by drawing a random number from a uniform distribution around the
cow specific probability. However, the elements of the logistic regression model, i.e.
the input parameters, were point estimates. We hereby assumed to be certain about
the true value of the herd’s specific probability to become diseased. Point estimates
are typically used in the state of nature of stochastic livestock simulation models
(Carpenter, 1988; Herrero et al., 1999; Groenendaal et al., 2002; Noordegraaf et al.,
2002; Christensen et al., 2008). Risk in decision making is underestimated when
using point estimates in the state of nature (Jørgensen, 2000a). In a simulation
model of a scavenging chicken production system, hyper distributions are specified
representing uncertainty concerning the true value for every parameter defined in the
model (McAinsh and Kristensen, 2004). Creating hyper distributions can be done in
different ways. The latter model used field data to specify the distributions, whereas
Jørgensen (2000a) developed a consistent way of creating prior distributions for
model input parameters given expert opinion and model output. In order to decide on
implementing a preventive action against a disease at a certain cost, it is not only
important to have an estimate on the expected revenue but also on the certainty on
this estimate. A more realistic estimate on model output and its variation results from
representing uncertainty in the model’s most important input parameters; disease
risks. A systematic way of creating hyper distributions for these parameters, where
data on cow level disease prevalence is used in combination with information on herd
level risk factors, has been described in Ettema et al. (2008). The second objective of
this study is to simulate the economic feasibility of an incentive that can reduce the
risk of lameness causing diseases by using hyper distributions describing disease
risks.
2. Material and Methods

2.1. SimHerd

SimHerd IV (Ostergaard et al., 2005), the model used in this study, is a dynamic (discrete, weekly time-stepping), stochastic and mechanistic Monte Carlo simulation model. SimHerd IV simulates the production and state changes in a dairy herd with additional young stock. The state of an animal is defined by age, parity, lactation stage, milk yield (actual and trades), body weight, culling status, reproductive status (oestrus and pregnancy), SCC (actual and trades) and disease status. 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 herd calculated. Drawing random numbers from relevant probability distributions trigger individual inherent and lactational milk yield potential and discrete events, such as heat detection, conception, abortion, sex and viability of the calf, diseases, involuntary culling and death. The production and development within the herd are, thus, determined indirectly by simulation of production and change in state of the individual cow and heifer.

Model behaviour can be controlled by a set of decision variables, which define certain production systems and management strategies. Involuntary culling was defined as a constant risk of 0.00193/wk for all cows. Voluntary culling was based on whether the cow became pregnant within the AI period. Cows with a milk yield higher or lower than the parity-specific herd-average were specified to have an AI period up to 287 or 245 days in milk, respectively. The AI periods were initiated 35 days after calving and cows were dried off 7 wk before calving. A cow not pregnant after the AI period was replaced when a heifer entered the herd and the particular cows were the lowest yielding candidates for voluntary culling. Non-pregnant cows producing less than 10 kg of milk per day were culled immediately. Reproductive efficiency was assumed by a conception rate to day 14 after conception of 0.43 and an estrus detection rate of 0.50, respectively. The first estrus cycles after calving and
reproductive disorders were modelled to have a detrimental effect on insemination and conception rates. Heifers got sold in case no cows were selected for culling and a maximum number of 200 cows was reached. Heifers were bought in case herd size reached a minimum number of 180 cows.

2.2. Parameterization of three lameness causing diseases

2.2.1. Categorization of diseases

In a previous simulation study, dairy cattle lameness was modelled as one health disorder where an assumption was made on the distribution of lesions causing the health disorder (Ettema and Ostergaard, 2006). Literature information concerning the underlying causes was weighed in according to the assumed distribution in order to get to one parameter estimate. In the current study, risk factors disease occurrence and parameters expressing the effect of the disease on production were specified for three categories of lameness causing diseases. Categorization of diseases was based on aetiology and agreement in risk factors and incorporated digital dermatitis (DD), interdigital hyperplasia (IH) and hoof horn diseases (HHD). The latter category is an aggregation of the hoof related diseases sole ulcer, double sole and white line disease. The reasoning behind this categorization is given in Ettema et al. (2008). There is however a small difference in disease categorization between this study and the current study. Instead of using an aggregation of three interdigital diseases as done in Ettema et al (2008), the current study considered interdigital hyperplasia as a separate disease and excluded the other two interdigital diseases (heel horn erosion (HHE) and interdigital dermatitis (ID)). An important assumption had to be made on disease duration. The chronic nature and incurability of IH in contrast to a shorter duration and curability of ID and HHE made it difficult to maintain the aggregation.
2.2.2. Hyper distributions

The fundamental difference with previous simulation studies performed with the Simherd model is the use of hyper distributions describing disease risk. Traditionally, state-of-nature parameters \((\Phi_o)\) in Simherd are described with fixed estimates. In the current study however, nine state-of-nature parameters representing three disease risks were described by a joint posterior distribution for three categories of parity.

As described by (Jørgensen, 2000b), a response function, i.e. simulation model can be evaluated for only one density \((\pi)\) function but, as is the case in the current study also for the joint probability distribution \(\pi_o(\Phi_o)\). In our context where the objective is to perform herd specific simulations and additional information is available on model parameters, the joint posterior distribution was formulated given observations \((y)\) done in the specific herd, \(\pi_o(\Phi_o | y)\). Bayesian statistics using Markov Chain Monte Carlo (MCMC) based methods, i.e. Winbugs (Spiegelhalter et al., 2004) were used to systematically create these distributions. The Gibbs sampler is the particular Markov chain algorithm used to generate the sequence of samples from the joint probability distributions. A full description of the Bayesian network is given in Ettema et al. (2008). The posterior distributions created with the network were based on prior knowledge on disease prevalence in the entire population, combined with different kinds and quantities of herd and cow specific evidence \((y)\). For every replicate of the simulation model, a state-of-nature \(\Phi_o(i)\) was randomly drawn from the joint probability distribution resulting in three parity specific logit values of three lameness causing diseases for a cow in the third stage of lactation. By running 1000 replicates with 1000 different random draws from the distributions, uncertainty around herd level risk is represented.

In this simulation study, the goal is to simulate certain management strategies in a specific (fictive) herd using different hyper distributions which represent different
levels of knowledge. In table 1 an overview is given of 9 different sets of marginal probability distributions used in this study for the probability’s logit value for having three lameness-causing diseases. In this table, only distributions for parity 3 are presented, the remaining 6 distributions for cows of parity 1 and 2 are not presented here. The 9 distribution sets represent knowledge available on the specific herd for which 9 different types and amounts of data are gathered.

Table 1

In set 1 there is only information available on herd-level risk factors present on the specific herd. As illustrated by the large standard deviations estimated in the Bayesian network (table 1), uncertainty concerning disease prevalence is large in case there is no cow-level information available. In addition to herd level risk factors, information on locomotion score of 45 cows has been collected in the specific herd and the joint posterior knowledge is represented by distribution set 2 and 3. The information on locomotion score indicates presence of clinical lameness among 0 and 40% of the cows, respectively. Due to the fact that presence of a disease does not necessarily result in clinical lameness (the conditional probability of lameness given the presence of the three diseases (P(Lame+|Disease+)) is less then 1), the information collected in herd 2 and 3 does not supply perfect knowledge on disease presence. As described in Ettema et al. (2008), P(Lame+|HHD+) is 0.48, compared to only 0.05 and 0.14 for DD and IH, respectively. The degree to which belief is updated for distribution set 2 and 3, indicated by the standard deviation of the hyper distributions, depends on the conditional probabilities for the three diseases. Instead of locomotion scores, the hoofs of 45 cows have been trimmed in set 4 and 5. The prevalence of each of the three diseases has been diagnosed and amounts to 7 and 40%, respectively. The same diseases prevalence has been found for sets 6 and 7, respectively. However, this evidence is based on 180 cows instead of 45. As
evidence accumulates, uncertainty on disease prevalence decreases. Finally, the same prevalence of 7 and 40% is diagnosed for sets 8 and 9, respectively, but in contrast to the other 7 sets, uncertainty about the prevalence is ignored. For sets 8 and 9 point estimates are used, which hereby represent the traditional way of describing disease risk in Simherd. To study the effect of disease risks’ different levels and degrees of certainty on the profitability of a preventive action estimated by simulation, draws from the joint distributions were used in Simherd.

By only using every 20th draw from the Gibb’s sampler, independence between the samples is guaranteed. The clustered structure of the data is represented in the statistical model described in the network (Ettema et al., 2008). Therefore the values drawn for different parities within one disease are positively correlated. If the risk in a herd is high for parity 1 cows, it is also high for parity 3 cows. Between diseases, samples are negatively correlated when the conditional distribution is given observations on clinical lameness. The fact that the three diseases have a common effect, i.e. lameness, creates dependency between diseases in case evidence is available on lameness. A high probability of DD being absent, given presence of lameness, increases our believe in the presence of the other two lameness causing diseases.

2.2.3. Calibration of disease prevalence

The effect of lactation stage (days in milk, DIM) on the risk of a disease in Simherd is specified with a 3-phase linear spline function (f(DIM)) (Ostergaard et al., 2005). For a cow at a certain DIM, the value of the spline function is subsequently used as the intercept in the logit function for disease onset. The values specified by the hyper distributions from the WinBugs model however, represent disease prevalence since this was the unit of the observations. In order to use information about prevalence from the hyper distribution in the logit function for disease onset in SimHerd, a calibration was necessary. The calibration process and its necessity for mechanistic
models like ours, is well described by Jørgensen (2000a). The challenge is to make knowledge on the model’s mechanisms and input parameters match knowledge on the observable output of the model. With respect to the former mentioned knowledge, the model’s mechanisms have been specified and documented and will not be adjusted in the calibration. It was therefore the input parameters that should be adjusted in order for the simulation model’s observable output, herd level prevalence, to match the prevalence described by the hyper distributions.

First of all, by assuming a value for disease duration, the simulation model was run with random draws from the hyper distributions and model output (prevalence) was subsequently evaluated. Accordingly, the simulation model was run again where all random draws were multiplied with the same factor until desirable model output was produced. The models output for incidence was therefore a result of the assumed duration and the calibrated prevalence.

A case of DD was assumed to be observable for 42 days after onset and it was further assumed that at an average herd level prevalence (20%, (Ettema et al., 2008)) a cow with DD can be observed as positive during 147 days of the lactation; i.e. a cow experiences on average 3.5 episodes of digital dermatitis. It is important to note here that only 1 out of the 3.5 episodes were assumed to get detected and treated. A cow that gets hit by DD in a lactation gets hit by 3.5 episodes and treated once. Figure 1 shows the results of the calibration process.

Figure 1

The grey box plots should be compared pair wise with the white box plots representing model output for DD prevalence resulting from using the respective set of distributions. The same calibration procedure was performed for the other 2 diseases and comparable results as presented in figure 1 were realized. Hereby it was assumed that HHD is observable during the entire lactation and a cow can only
suffer from one episode during one lactation. It was hereby also assumed that 40% of all cows go through a second episode of HHD (Lischer, 2000). Interdigital Hyperplasia was assumed to be chronic and therefore also present later on and in following lactations after first occurrence (Enevoldsen et al., 1991).

2.2.4. Risk factors

Depending on the cow’s lactation stage, parity, milk yield potential, previous cases of the disease and access to pasture a cow specific probability of becoming diseased is calculated for every week of simulation. The parity specific estimates drawn from the joint distributions were transformed from prevalence into lactation stage specific risks for disease onset. Parameters of the earlier mentioned spline function were calibrated in a way that resulted in correct model output for prevalence in the different lactation stages, as reported in the logistic regression analysis of this data (Ettema et al., 2008).

The modelled herd in this study implement zero-grazing in its management (table 1), there was therefore no high or a low risk season specified. Finally, milk yield potential was quantified as a risk factor for all three lameness causing diseases. The increased risk of contracting a disease in comparison to an average producing cow was quantified with an OR per kg of energy corrected milk (ECM) that the cow has the potential to produce more in comparison to an average producing cow. For all three lameness causing diseases this OR was set at 1.046 (Fleischer et al., 2001). There were no disease specific estimates available.

2.2.5. Effect parameters

The effects of lameness on production, reproduction and survival data are summarized in table 2. A study of the literature referred to in the table was used to specify these effect parameters
Feed intake was modelled as the intake of net energy measured in feeding units (FE) necessary to realize milk production, maintenance and fetus growth. These three processes are described by functions (lactation curve, body condition curve and growth curve, respectively). As a result of lower milk yield and weight loss, feed intake gets reduced with the corresponding amounts.

The estimate for reduced milk yield due to clinical lameness caused by HHD was based on the study of (Bicalho et al., 2008). Their estimate of a daily milk loss of 3.7% over the entire lactation was considered least biased, since it was based on a retrospective matched cohort design and an analysis of covariance. Besides, the cases of clinical lameness in their study were caused by diseases of the lamanitic kind, which fitted our definition of HHD best. Each lame cow in this study was treated with an orthopaedic block. Since this is not common practice for the treatment of double soles, which comprise 27% of the HHD, it was assumed that double soles have a less severe impact on milk yield loss. Therefore 27% of the cases of HHD were modelled as a mild case, which reduce milk yield with a proportion of only 0.25 of the estimate found by.

To the authors knowledge, there has not been performed a study that has given an unbiased estimate for milk loss caused by DD or IH. However, the study by Hernandez et al. (2002) found a 1.8% lower milk yield in lactations where cows were treated for clinical lameness due to digital dermatitis. The same result was found by Argaez-Rodriguez et al. (1997), neither of the studies found this result to be significant. As illustrated by Bicalho et al. (2008) it’s hard to find a significant effect of lameness on milk yield in a retrospective cohort design using analysis of variance. However, due to a lack of better estimates the loss of 1.8% was used in this study for both DD and IH. In the paragraph on calibration of model input parameters, it was mentioned that a cow hit by DD on average gets hit 3.5 times. In the study of
Hernandez et al. (2002) no information on the number of episodes or the duration of the episode was available. For the current study it was assumed that the 1.8% lactational milk loss is spread out over the 3.5 cases per affected cow. Every episode of DD therefore resulted in a 0.5% milk loss.

2.2.6. Treatment costs of lameness causing diseases

The costs of treating a lame cow differ across countries, across farms, across underlying diseases causing lameness and across people responsible for treating the cow. Finally, the selection criteria for treatment and therefore the severity of the treated case of lameness contribute to the variation. In the calculations by Guard (1999) treatments costs including veterinary fees, hoof trimmer fees, drugs and farmer labor are set at $23 per case ($1 = €0.75). In the study of Enting et al. (1997) treatment and labour of veterinary and farmer amounted to €24. In the study of Kossaibati and Esslemont (1997) treatment costs for a single case of lameness caused by a digital disease, interdigital disease and sole ulcer were £47.5, £31.4 and £66, respectively (£1 = €1.12). In our previous simulation study the costs of treatment of clinical lameness was set on €60.5 (Ettema and Ostergaard, 2006).

All prices and treatment costs used to quantify the technical output of the simulation model were set in a way that is representative for a typical modern Danish dairy farm and are presented in table 3.

Table 3

Treatment costs for this study were based on current tariffs, rates and procedures used by Danish veterinarians, professional hoof trimmers, farmers or during routine hoof trimming. For this study it was assumed that an equal proportion (25%) of lameness caused by DD and HHD gets treated by each of the four procedures mentioned above. For DD the earlier mentioned number of 3.5 episodes per affected
cow was used to divide treatment costs with, as was done for the effect of DD on milk yield. In other words, only 1 out of 3.5 cases gets treated. It was finally assumed that a case of HHD gets treated a second time in 40% of the cases (Lischer, 2000) which was also assumed in the economic analysis of Kossaibati and Esslemont (1997). For the treatment of Interdigital Hyperplasia (IH), it was assumed that none of them get treated as an acute case, but all at periodic trimming.

2.3. Design of the simulation study

2.3.1 Economic impact per case of lameness causing disease

In scenario 1 to 4, fixed estimates indicating a high risk for all diseases (distribution set 9) were used where disease risk is set to 0 for DD, IH and HHD in scenario 2, 3 and 4, respectively. This was done in order to quantify the economic impact of every single disease. In scenario 5 to 8, the same pair wise comparison was performed using fixed estimates indicating a low risk for all diseases (distribution set 8). Disease risk in all four scenarios was described with point estimates, rather than hyper distributions. This was done for two reasons. First of all, by setting disease risk at zero a point estimate is used and uncertainty is ignored; comparison with a scenario where hyper distributions are used would not be consistent. Secondly, simulating a scenario where disease risk is zero is not a realistic scenario in terms of what is practically feasible. This scenario was run to get a precise estimate of the economic impact of the three diseases.

2.3.2 Economic feasibility of halving the risk of all lameness causing diseases

For scenario 9 to 17, 1000 samples were drawn from 9 different sets of joint posterior distributions specifying parity specific disease risk for the three lameness causing diseases (set 1 in scenario 9, set 2 in scenario 10, etc.). Accordingly every replicate was simulated by using the respective draws. In order to estimate the economic benefit of an incentive that could half the risk of all lameness causing diseases, the
simulation model was run with the same 1000 draws in scenario 18 to 26, where the
weekly disease risk that resulted from the calibration process, was divided by 2. By
running these 18 scenarios, an incentive that halves disease risk can be evaluated
for 9 different levels and degrees of certainty on disease prevalence.

2.3.3 Herd specific estimates

Both the estimate of the economic impact of a single disease and feasibility of an
incentive that can half disease risks were estimated in a herd with average and poor
reproductive performance in scenarios 27 to 52. The same procedure as described in
the previous two paragraphs was followed, with the only difference that the
conception rate to day 14 after conception was set to 0.38 instead of 0.43 and estrus
detection rate was set to 0.40 instead of 0.50. Parameters in this herd with poor
reproduction were set in a way that resulted in a 14-day higher calving interval and a
4% higher replacement rate.

2.4 Simulation procedure and analysis of the results

A scenario where the risk, described with point estimates, for all lameness causing
diseases was at a level that resulted in a prevalence representative for the population
was simulated over 10 years; the resulting herd was used as initial herd for all other
scenarios in order to eliminate the effect of the arbitrary start herd. After creation of
this initial herd, all scenarios were simulated over 20 years with 1000 replications.
The high number of replications and long simulation horizon were chosen in order to
obtain a precise estimate of the results. Total margin was calculated as the sales
income minus the variable costs for cows and additional young stock. Labour and
management costs were generally not included, except for the labour involved with
treatment of diseases (table 3). Each replication of the model must be considered as
an independent observation. To avoid the influence of the initial herd, only the
average results over the last fifteen years of the twenty-year simulation were studied.
Based on analysis of variance, least significant differences were estimated for the pair wise comparison of scenarios with different disease levels. By using the same draws from the hyper distributions for the two different disease levels, each replicate of one scenario has a unique relationship with a particular replicate of the other scenario. Testing of the means of the two results were therefore done with a paired t-test. Interpretation of the significance of results should be done with care, since a statistically significant difference realized by the high number of replications can be very small from a practical perspective.

3. Results

3.1 Technical and economic impact of three lameness causing diseases

In table 4 and 5 technical and economic consequences are presented of a scenario were all three disease risks are at a high level in contrast to 4 scenarios where the risk of each disease is set to zero and where risk of all three diseases is halved.

Table 4

In a herd with a high risk for DD, 91% of all cows get affected with DD at least once. On average, affected cows contract 4.6 episodes of DD and are therefore affected during 193 days of their lactation. By halving the cow’s risk, the total number of cases per cow-year drops by 45%, 23 fewer cows get affected by DD and the average number of episodes per affected cow drops from 4.6 to 3.4. Halving the risk of IH and HHD results in 45% and 42% fewer cases per cow-year, respectively. The average number of cows present in the herd increased with 0.15, 0.04, 0.32 and 0.23 when the risk for DD, IH, HHD was set to zero and when all three disease risks was halved, respectively. Besides this figure, it also becomes apparent from the change in replacement rate and sold heifers that HHD has the largest impact on herd...
demography. Due to the lower replacement rate, despite the lower calving interval for HHD-zero, fewer calves are born per cow-year. It is also therefore that the average number of young stock present (heifer-years) is lower. Milk yield per cow-year is 60 to 190 kg higher in the alternative scenarios.

Table 5

From the results presented in table 4 and 5, it can be calculated that the average costs per single case of DD, IH and HHD is €31.1, €66.6 and €261.4, respectively. For the costs per case of HHD a second treatment, necessary in 40% of the cases, is included. For DD, this is the costs of a single case, which was assumed to last 42 days. Considering the fact that in this high risk herd, cows that are lame due to DD on average suffer from 4.6 cases per lactation; the loss per case of clinical lameness caused by DD in a high risk herd is €143.0.

3.1.1 Herd specific estimates

Low risk herd, with average reproduction

The above described contrast between high risk and zero risk for each of the diseases was also analyzed for a herd where disease risks are low; resulting in a prevalence of 7%. The estimated costs per cow-year for DD, IH and HHD are €21.7, €5.1 and €26.8, respectively. The estimated costs per single case of lameness causing disease are €31.9, €62.0 and €248.7, for DD, IH and HHD, respectively. Based on the least significant differences, the costs per case estimated in contrast to a high or low risk, are not significantly different. With on average 2.1 episode of DD per affected cow, the loss per affected cow in a low risk herd is €67.0. When halving the risk of all diseases in a low risk herd, instead of €123.5, the margin per cow-year increases with €29.3.
High risk herd, with poor reproduction

The most important technical and economic effects of the above described contrast between high risk and the 4 alternative scenarios are displayed in table 6 for a herd with poor reproductive performance.

Table 6

Compared to a herd with average reproduction, eliminating one of the lameness causing diseases has a larger impact on the number of cow-years in the herd. The change in replacement rate is actually less in a herd with poor reproduction when HHD is eliminated and all disease risks are halved; cows are not replaced since there are no heifers available to replace them with. Instead of selling heifers, as was done in a herd with average production, 4 heifers per 100 cow-years need to be bought. By eliminating HHD and halving all three disease risks, the problem of heifer shortage is almost gotten rid off. The estimated costs per single case of lameness causing disease are €46.4, €125.6 and €520.8, for DD, IH and HHD, respectively.

Low risk herd, with poor reproduction

In a herd with poor reproduction and a low risk for all diseases, there is no problem with maintaining herd size. The increase in cow-years when eliminating the single diseases and halving the risk of all three of them is therefore of the same magnitude as was the case for a herd with average reproduction and high disease risk. The estimated costs per cow-year for DD, IH and HHD are €31, €6.1 and €26.3, respectively. The estimated costs per single case of lameness causing disease are €46.3, €89.9 and €272.3, for DD, IH and HHD, respectively. Based on the least significant differences, the costs per case of DD estimated in contrast to a high or low risk are not significantly different. When halving the risk of all diseases in a low risk herd, instead of €158.3, the margin per cow-year increases with €36.7.
In table 7 all herd specific estimates for costs per case of lameness causing disease are presented along with the estimated increase in margin-per-cow year when halving all disease risks.

Table 7

3.2. Economic feasibility of halving the risk of all three diseases using 9 different sets of distributions

In table 4 and 5 technical and economic consequences are presented of a scenario where all three disease risks are at a high level in contrast to a scenario where risk of all three diseases is halved. This was done with fixed estimates for disease risk; i.e. with set 9. In figure 2, the change in gross margin per cow-year is displayed when 9 different sets of hyper distributions are used and all three disease risks are halved.

Figure 2

The resulting median change in margin per cow-year and the SD for 9 different sets with average and poor reproduction are displayed in table 8.

Table 8

In case the only thing known about the specific herd is the fact reproductive efficiency is average, herd size is over 125 cows, footbaths are not regularly used and zero grazing and TMR is implemented, an incentive that halves all three disease risks is expected to result in a higher margin per cow-year of €78. This estimate is uncertain, but 95% sure to be between €25 and €130. If accordingly an effort is done to collect
information on the prevalence of lame cows, prevalence of hoof lesions among 45 and 180 cows indicating that the problem is small (set 2, 4, 6, respectively), the expected revenue resulting from the incentive decreases and believe in the estimate increases. Reversely, by adding more proof of lameness and the underlying disease being present in the herd (represented by distribution set 3, 5, 7) the expected revenue increases, as does certainty about it. For a herd with poor reproduction the change in gross-margin is larger for all 9 distribution sets (information levels).

4. Discussion

4.1 Calibration and direct use of data on prevalence

To the author's knowledge, information on prevalence collected in the field has not been used directly and systematically in a cow-based simulation model of a dairy herd. The problem of only having knowledge on observable output from the simulation model (disease prevalence) and making it coherent with knowledge on the simulation model's structure and input parameters is a very relevant one for mechanistic simulation models like ours. As described by Jørgensen (2000a) prior distributions are adjusted until desirable model output is produced. In our study however, the prior distributions were created systematically using Bayesian statistics. The process of adjusting the prior distributions was not performed by creating new distributions; instead each random draw from the distributions was multiplied with a "factor". When comparing model output on disease prevalence to prevalence described by the hyper distributions (figure 1), it can be concluded that the simulation model's result are distributed more normally than the hyper distributions. The distributions are less skewed and fewer or no extreme values are produced by the model. Our current study has demonstrated the concept of using field data in a consistent way. This is one of two improvements to the model's functionality; the other improvement is the consistent handling of parameter uncertainty. The marginal distributions represent knowledge from the population and herd specific knowledge.
on risk factors. The designed framework enables inclusion of cow specific observations where the relationship between diseases and between diseases and their common cause (lameness) is represented correctly.

4.2 Disease duration

Best guesses for disease duration have been used. To the author’s knowledge there is no literature available that describes the duration of a single case of digital dermatitis. In the description of the different disease stages of DD, one diseased animal goes through all stages in 71 days, where the active form of DD is treated at day 50 (Dopfer et al., 1997). This however is just a single example of a case of DD that gets treated. In a study where the inefficacy of three commercial hoof-care products is proven, a spontaneous cure rate across treatments of digital dermatitis of 0.54 is found (Thomsen et al., 2008). This observation window was however 8 weeks; cases of DD that were diagnosed at the study’s first observation disappeared within 56 days without any treatment. Other studies have attempted to describe the clinical course of digital dermatitis, but observations were done with fairly large intervals (3 weeks, (Holzhauer et al., 2008b)) or during only a time span of 4 weeks (Holzhauer et al., 2008a). Nothing reasonable can be said on either duration or reoccurrence of DD. For this study the duration for a single case of DD is assumed to be 42 days. Furthermore, it is assumed that a cow that has had one episode of DD is at higher risk of contracting another episode. Whether this is a problem cow that persists in the infectious stage of DD (Holzhauer et al., 2008b) or a reoccurring case is not very relevant for the approach of simulating the disease in this study; i.e. one long lasting disease compared to several short lasting episodes results in the same prevalence and the same number of animals hit by DD.

The relationship between prevalence and incidence can be described by

\[ P = \frac{I \times D}{(I \times D + 1)} \] (Dohoo et al., 2003). This formula can be rewritten where incidence becomes a function of prevalence and duration; 

\[ I = \frac{(P/D)}{(1-P)}. \] Assuming duration to
be twice as long, results in half the incidence, given certain prevalence. The above described formula is only valid in stable populations, but by assuming different durations, a much comparable relationship was found in a simulated dairy herd. Besides a result on overall incidence per cow-year, an estimate on the number of times an affected cow is hit is also derived from the simulation model's output. This figure of 3.5 cases is used to divide the effect on milk production and treatment costs by. In case a longer duration would have been assumed, a lower number of hits per affected cow would have been the result which then would have been used to divide reduced milk yield and treatment costs by. For modelling a disease like DD a number of important assumptions are based weak evidence on duration, reoccurrence rates, effects on production and treatment frequency.

Since both HHD and IH were assumed to be present during the entire lactation, it was not possible for these diseases to reoccur during lactation. The same considerations and reasoning as described above for DD have been used in assuming the duration of HHD,

### 4.3 Cost per case of three lameness causing diseases

The estimated economic impact of a single case of DD, ID and HHD in a herd with average reproduction and a high level of diseases was €31, €67 and €261, respectively. In the herd with average reproduction, the estimated loss per case was not different in case disease prevalence was low in the basic scenario. However, considering that a cow affected with DD gets hit 2.2 and 4.6 times in a herd with low and high risk, respectively, the economic impact of a cow affected with lameness caused by DD varies from €67 to €143. The estimated costs per case of OID and HHD were only 7 and 5% lower for the low risk herd compared to the high risk herd respectively, though not significant despite the high number of replicates. The costs per foot-lame cow were estimated on €104 by Enting et al. (1997). This study economically evaluated the effects of clinical lameness found in a data study by
partial budgeting. Difference between the studies’ outcome can to a certain extent be explained transparently by differences in the estimates used on cow level for milk loss, reduced fertility, increased culling risk and treatment costs. Due to differences in modelling techniques, a further comparison is difficult; Enting et al. (1997) quantified the economic impact of an extra day open and a culling with a certain monetary value. Whereas in Simherd the herd’s economic performance is a result of the simulated production and reproduction of the individual animals.

In a herd with poor reproduction, the economic impact of a case of DD, OID and HHD were 48%, 88% and 100% higher, compared to a herd with average reproduction. It is especially the average herd size, which can not be maintained when all diseases are at a high level, that is responsible for the lower total margin. On cow level the diseases have the same relative detrimental effect on milk production and reproduction. However, due to the fact that a herd with poor reproduction already has difficulties with maintaining herd size the detrimental effects of diseases are even more costly. In addition to selling one heifer less, as is the effect of a replacement in a herd with average reproduction, a stable space remains empty for a certain period in a herd with poor reproduction. For this study a minimal number of 180 cows has been specified; in case herd size drops below this number, heifers are purchased. If a higher threshold for heifer purchase would have been chosen, number of cow-years would have been affected less. However, it can be expected that more than 4 heifers (table 6) would have to be purchased. These different results illustrate the importance of a mechanistic simulation model.

(Kossaibati and Esslemont, 1997) estimated the costs per case of lameness caused by digital diseases and sole ulcer, both aggregated into HHD in our study, on €343 and €602. This is on average €473 and thereby lower and higher than the estimate found in our study in a herd with poor and average reproduction, respectively. The differences in cow-level estimates and modelling techniques as mentioned in the earlier comparison, contribute to the studies’ different results. Kossaibati and
Esslemont (1997) used a lactational yield loss of 3% for a severe case of sole ulcer. In our study, the yield loss on cow level caused by HHD was set 23% higher at 3.7%. However, if the higher amount of milk produced in the HHD-zero compared to the high risk scenario, is divided by the number of HHD cases in the high risk scenario, a lower yield of 404 kg can be attributed to a single case of HHD. This is 4.4% of the yield per year-cow. This is a direct effect of a higher yield of animals not affected by HHD, but also an indirect effect of a lower calving interval, more multiparous cows in the herd (lower replacement rate) and more days dry per cow-year.

Finally, comparing our earlier simulation study on lameness as one symptom of many health disorders shows an economic impact of €192 per case of lameness. Categorizing lameness as the cause of different diseases, as done in the current study, enabled specification of specific values for diseases’ effects. This was especially important for the effect on conception chance, involuntary culling and mortality, and thereby resulted in estimated losses varying from €31 per single episode of DD up to €261 for clinical lameness caused by HHD. For lameness as one health disorder, the estimated losses were also higher in herd with low pregnancy chance (45% higher) and low heat detection efficiency (16% higher) (Ettema and Ostergaard, 2006).

4.4 Interpretation of results for different hyper distributions

The results presented in figure 2 and table 8 should be interpreted in terms of the expected economic profitability of an incentive, given different degrees of belief in disease risk. Assuming the fact that these results are normally distributed and that full uncertainty is represented in our simulation model, a probability can be calculated for a certain incentive, costing €X per cow-year, to be profitable. With the integral of the normal distribution from X to plus-infinity, the probability that the economic gain is larger than X is calculated. For the first herd with average reproduction, the expected profitability of the incentive is €78 with a standard deviation of 26. By assuming that
the incentive costs €40 per cow-year, the best guess of the expected profit of this
decision is €38 per cow-year. The probability that the incentive’s revenues exceed
the costs (the incentive results in a profit) is 0.92. When subsequently more
information is added on lameness prevalence being 0%, hoof trimming on 45 cows
and hoof trimming on 180 cows indicating a 7% prevalence of all diseases, the
expected profitability of this incentive decreases as shown in table 8. Besides, the
probability of this incentive being profitable decreases to 0.75, 0.51 and 0.35,
respectively. Information on disease risk accumulates and the simulation model is
run with the resulting hyper distributions describing disease risk. Subsequently,
certainty about the model’s outcome increases and for this particular example,
believe in profitability decreases.

Since only 9 of the simulation model’s parameters are described by a hyper
distribution, over 1000 parameters remain fixed. Uncertainty in the model’s outcome
should therefore not be assumed as fully represented.

4.5 Opportunities for application

The specific herd and data used to condition the posterior estimates on were fictitious
and served merely as an illustration of Simerd’s use of hyper distributions.

An interesting application of the Bayesian Network would be one where information
on both lameness prevalence and hoof trimming registration would be combined. It is
likely that real life data would supply evidence on certain disease being a problem
instead of all diseases being prevalent among either 7% or 40% of the cows, as the
network was illustrated with. In addition, preventive strategies mainly effective
against certain diseases could be evaluated; using rubber floors only benefits hoof
horn diseases (Benz, 2002) whereas topical treatment or footbaths mainly benefit the
infectious diseases (Shearer and Hernandez, 2000; Manske et al., 2002).
Illustration of this study’s three new main concepts, i.e. using hyper distributions, using field data on prevalence and division of three causes of lameness, was addressed in this study. Demonstrating a real life application is an obvious next step.

4.6 Dynamic aspect of the simulation model

The network creating the hyper distributions is static, in contrast to the simulation model being dynamic. The creation of hyper parameters describing disease risk is done for the present situation in the specific herd. Every sample from the distribution is used by the simulation model to forecast the cows’ life in weekly steps. Hereby, the value of the drawn sample does not change in time. However, a more correct approach would have been a changing disease risk in time due to herd effects or preventive measures. Correlation of disease risk in the future herd with the risk in the present situation decreases as time goes by. Without updating the network with new herd specific information, the best guess for the future disease risk is to move towards the population mean. Besides, as time goes by, certainty about the disease risk decreases. In this first set-up of an existing Monte Carlo simulation model using hyper distributions, the network was kept static.

5. Conclusion

The economic impact of the three lameness causing diseases digital dermatitis, interdigital hyperplasia and hoof horn diseases was estimated on €31, €67 and €261, respectively. Different estimates were found for herds with different levels of disease risk and reproductive efficiency. The use of hyper distributions describing disease risk by an existing dynamic, stochastic and mechanistic simulation model of a dairy herd has been demonstrated. Through the described process of calibration, systematic use can be made of different types and amounts of field data on disease prevalence. The uncertainty in input parameters gets reflected in the uncertainty of the simulation model’s output, which is important in decision support in livestock
systems. An improvement has been made in describing uncertainty, it should however be realized that uncertainty on model outcome is still underestimated.

References


Thomsen, P.T., 2008. Involuntary culling during the first 100 days of lactation.


**Figure legends:**

**Figure 1:** Prevalence of DD as described by hyper distributions (model input, grey boxes) and prevalence of DD as simulated by Simherd (model output, white boxes) for 9 different sets of hyper distributions describing disease risk.

**Figure 2:** Change of gross margin per cow-year as an effect of halving the risk of all three lameness causing diseases when using 9 different sets of hyper distributions describing disease risk.
Figure 1: Prevalence of DD as described by hyper distributions (model input, grey boxes) and prevalence of DD as simulated by Simherd (model output, white boxes) for 9 different sets of hyper distributions describing disease risk.
Figure 2: Change of gross margin per cow-year as an effect of halving the risk of all three lameness causing diseases when using 9 different sets of hyper distributions describing disease risk.
Table 1

Marginal posterior distributions of the logit of the probability of a third parity cow, in the third stage of lactation having digital dermatitis (DD), interdigital hyperplasia (IH) and hoof horn disease (HHD) for 9 different situations in case information is collected on only herd level* (1), lameness observations (2,3), disease diagnoses at trimming (4-7) and perfect knowledge on disease prevalence (8,9).

<table>
<thead>
<tr>
<th>Set</th>
<th>DD</th>
<th>IH</th>
<th>HHD</th>
<th>LAME</th>
<th>N</th>
<th>μ</th>
<th>σ</th>
<th>μ</th>
<th>σ</th>
<th>μ</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-1,43</td>
<td>1,27</td>
<td>-2,38</td>
<td>0,84</td>
<td>-0,30</td>
<td>1,05</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0%</td>
<td>45</td>
<td>-1,65</td>
<td>1,18</td>
<td>-2,48</td>
<td>0,86</td>
<td>-1,56</td>
<td>0,77</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>40%</td>
<td>45</td>
<td>-1,28</td>
<td>1,28</td>
<td>-2,17</td>
<td>0,89</td>
<td>1,41</td>
<td>0,70</td>
</tr>
<tr>
<td>4</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td>-</td>
<td>45</td>
<td>-2,62</td>
<td>0,53</td>
<td>-2,43</td>
<td>0,52</td>
<td>-1,60</td>
<td>0,48</td>
</tr>
<tr>
<td>5</td>
<td>40%</td>
<td>40%</td>
<td>40%</td>
<td>-</td>
<td>45</td>
<td>-0,60</td>
<td>0,32</td>
<td>-0,36</td>
<td>0,33</td>
<td>0,34</td>
<td>0,32</td>
</tr>
<tr>
<td>6</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td>-</td>
<td>180</td>
<td>-2,74</td>
<td>0,30</td>
<td>-2,41</td>
<td>0,31</td>
<td>-1,82</td>
<td>0,29</td>
</tr>
<tr>
<td>7</td>
<td>40%</td>
<td>40%</td>
<td>40%</td>
<td>-</td>
<td>180</td>
<td>-0,53</td>
<td>0,17</td>
<td>-0,17</td>
<td>0,19</td>
<td>0,37</td>
<td>0,18</td>
</tr>
<tr>
<td>8</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td>-</td>
<td>-</td>
<td>-2,59</td>
<td>-2,59</td>
<td>-2,59</td>
<td>-2,59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>40%</td>
<td>40%</td>
<td>40%</td>
<td>-</td>
<td>-</td>
<td>-0,40</td>
<td>-0,40</td>
<td>-0,40</td>
<td>-0,40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Herd size >125, no regular use of footbaths, zero grazing and the use of TMR
**Table 2**

Assumed effects of digital dermatitis (DD), interdigital hyperplasia (IH) and hoof horn diseases (HHD) on production, reproduction and survival

<table>
<thead>
<tr>
<th></th>
<th>DD</th>
<th>IH</th>
<th>HHD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced milk yield, per lactation †</td>
<td>0.5%</td>
<td>1.8%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Daily body weight loss (%)</td>
<td>0.03</td>
<td>0.03</td>
<td>0.12</td>
</tr>
<tr>
<td>Relative decline per day in the effect on weight loss</td>
<td>-0.026</td>
<td>-0.026</td>
<td>-0.026</td>
</tr>
<tr>
<td>Reduced conception rate, risk ratio</td>
<td>0.89</td>
<td>0.86</td>
<td>0.43</td>
</tr>
<tr>
<td>Duration reduced conception rate, days</td>
<td>42</td>
<td>e.o.l.</td>
<td>140</td>
</tr>
<tr>
<td>Risk * of involuntary culling</td>
<td>0.14%</td>
<td>0%</td>
<td>3.64%</td>
</tr>
<tr>
<td>Risk * of sudden death/euthanasia</td>
<td>0.16%</td>
<td>0%</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

References used:

1 (Argaez-Rodriguez et al., 1997; Hernandez et al., 2002; Bicalho et al., 2008)

2 (Van Arendonk et al., 1984; Enting et al., 1997)

3 (Collick et al., 1989; Argaez-Rodriguez et al., 1997; Melendez et al., 2003)

4 (Thomsen et al., 2004; Enemark, 2007)

5 (Rajala-Schultz and Gröhn, 1999; Thomsen et al., 2004; Thomsen, 2008)

6 Until the end of lactation

* during week of onset

of footbaths, zero grazing and the use of TMR
<table>
<thead>
<tr>
<th>Factor</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Milk</strong></td>
<td>€0.38 per kg ECM&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Livestock</strong></td>
<td>Slaughter cows: €0.94 per kg BW; Bull calves: €107; Springing heifers: €1477; Dead cows: -€72/animal</td>
</tr>
<tr>
<td><strong>Feed cows</strong></td>
<td>Total ration for cows €0.20 per FE&lt;sup&gt;2&lt;/sup&gt; and for dry cows €0.16 per FE</td>
</tr>
<tr>
<td><strong>Feed heifers</strong></td>
<td>Milk replacer: €2.4 per kg; Concentrates: €0.30 per FE, Roughage: €0.17 per FE, Grazing first and second year: €0.60 and €1.20/d</td>
</tr>
<tr>
<td><strong>Veterinary cost</strong></td>
<td>HHD: €52; DD: €47; IH: €8; Milk fever: €95; Dystocia: €107, Retained Placenta: €38; Metritis: €44; Left displaced abomesum: €89; Ketosis: €44; Mastitis: €54</td>
</tr>
<tr>
<td><strong>Other costs</strong></td>
<td>Cows&lt;sup&gt;3&lt;/sup&gt;: €40 per cow/yr; Heifers&lt;sup&gt;3&lt;/sup&gt;: €13 per heifer/yr; AI: €16/AI</td>
</tr>
<tr>
<td><strong>Interest rate of herd value</strong></td>
<td>4% per year</td>
</tr>
</tbody>
</table>

<sup>1</sup> ECM = Energy corrected milk

<sup>2</sup> FE = Feeding unit

<sup>3</sup> Average costs for bedding, milk recording, pregnancy test, additional veterinary assistance and drugs
### Table 4

Mean and standard deviation (SD) of the annual technical effects in a scenario with a high risk of all lameness causing diseases and the mean differences with alternative scenarios where DD, IH and HHD risk are set to zero and all three risks are halved.

<table>
<thead>
<tr>
<th></th>
<th>High risk</th>
<th>Difference with alternative scenarios</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>DD-zero</td>
<td>IH-zero</td>
<td>HHD-zero</td>
<td>ALL-half</td>
<td>LSD^c</td>
</tr>
<tr>
<td>Cow-years</td>
<td>197,9</td>
<td>0,13</td>
<td>+0,15</td>
<td>+0,04</td>
<td>+0,32</td>
<td>+0,23</td>
<td>0,01</td>
</tr>
<tr>
<td>Milk yield, kg ECM^a</td>
<td>9140</td>
<td>41,4</td>
<td>+190,3</td>
<td>+60,7</td>
<td>+148,4</td>
<td>+176,2</td>
<td>3,84</td>
</tr>
<tr>
<td>Feed intake †, FE^b</td>
<td>6528</td>
<td>19,2</td>
<td>+121,6</td>
<td>+32,4</td>
<td>+81,0</td>
<td>+103,8</td>
<td>1,78</td>
</tr>
<tr>
<td>Replacement rate</td>
<td>41,1</td>
<td>0,87</td>
<td>-1,73</td>
<td>-0,57</td>
<td>-4,26</td>
<td>-2,90</td>
<td>0,08</td>
</tr>
<tr>
<td>Calves born †</td>
<td>1,07</td>
<td>0,009</td>
<td>+0,002</td>
<td>+0,004</td>
<td>-0,011</td>
<td>-0,002</td>
<td>0,001</td>
</tr>
<tr>
<td>Inseminations †</td>
<td>2,46</td>
<td>0,032</td>
<td>-0,042</td>
<td>-0,043</td>
<td>-0,098</td>
<td>-0,082</td>
<td>0,003</td>
</tr>
<tr>
<td>Calving interval</td>
<td>401</td>
<td>1,5</td>
<td>-2,4</td>
<td>-1,4</td>
<td>-3,4</td>
<td>-3,5</td>
<td>0,12</td>
</tr>
<tr>
<td>Days dry †</td>
<td>32</td>
<td>0,4</td>
<td>+1,0</td>
<td>+0,5</td>
<td>+1,6</td>
<td>+1,3</td>
<td>0,02</td>
</tr>
<tr>
<td>Heifer-years</td>
<td>198,1</td>
<td>5,13</td>
<td>+0,65</td>
<td>+0,69</td>
<td>-1,84</td>
<td>-0,21</td>
<td>0,40</td>
</tr>
<tr>
<td>Sold heifers *</td>
<td>3,8</td>
<td>0,09</td>
<td>+1,8</td>
<td>+0,7</td>
<td>+3,8</td>
<td>+2,8</td>
<td>0,005</td>
</tr>
<tr>
<td>DD prevalence, %</td>
<td>41</td>
<td>1,2</td>
<td>-0,2</td>
<td>-0,1</td>
<td>-18,7</td>
<td>-18,7</td>
<td>0,09</td>
</tr>
<tr>
<td>cases *</td>
<td>420</td>
<td>4,4</td>
<td>-1,2</td>
<td>-2,3</td>
<td>-189,6</td>
<td>-189,6</td>
<td>0,34</td>
</tr>
<tr>
<td>affected cows *</td>
<td>91</td>
<td>1,0</td>
<td>+0,2</td>
<td>-0,5</td>
<td>-23,4</td>
<td>-23,4</td>
<td>0,07</td>
</tr>
<tr>
<td>cases per cow</td>
<td>4,6</td>
<td>0,05</td>
<td>-0,02</td>
<td>+0,00</td>
<td>-1,21</td>
<td>-1,21</td>
<td>0,003</td>
</tr>
<tr>
<td>IH prevalence, %</td>
<td>38</td>
<td>1,2</td>
<td>+0,0</td>
<td>-0,2</td>
<td>-16,9</td>
<td>-16,9</td>
<td>0,09</td>
</tr>
<tr>
<td>cases *</td>
<td>40</td>
<td>1,0</td>
<td>+0,2</td>
<td>-0,3</td>
<td>-17,9</td>
<td>-17,9</td>
<td>0,08</td>
</tr>
<tr>
<td>HHD prevalence, %</td>
<td>37</td>
<td>1,1</td>
<td>+0,2</td>
<td>+0,2</td>
<td>-15,5</td>
<td>-15,5</td>
<td>0,09</td>
</tr>
<tr>
<td>cases *</td>
<td>49</td>
<td>1,1</td>
<td>+0,2</td>
<td>+0,2</td>
<td>-20,6</td>
<td>-20,6</td>
<td>0,08</td>
</tr>
<tr>
<td>Mastitis cases *</td>
<td>40</td>
<td>1,3</td>
<td>+1,0</td>
<td>+0,4</td>
<td>+2,1</td>
<td>+1,5</td>
<td>0,001</td>
</tr>
<tr>
<td>Other treatments *</td>
<td>31</td>
<td>1,3</td>
<td>+0,6</td>
<td>+0,3</td>
<td>+1,0</td>
<td>+0,9</td>
<td>0,001</td>
</tr>
<tr>
<td>Dead cows *</td>
<td>7,1</td>
<td>0,47</td>
<td>-0,63</td>
<td>+0,02</td>
<td>-1,70</td>
<td>-1,00</td>
<td>0,001</td>
</tr>
</tbody>
</table>

^a ECM = energy corrected milk

^b FE = feeding unit
LSD = Least significant difference ($p<0.05$)

† per cow-year

* per 100 cow-years
Table 5

Mean and standard deviation (SD) of the annual economic effects in a scenario with a high risk of all lameness causing diseases and the mean differences with alternative scenarios where DD, IH and HHD risk are set to zero and are halved, respectively.

<table>
<thead>
<tr>
<th></th>
<th>High risk Mean</th>
<th>High risk SD</th>
<th>Difference with alternative scenarios</th>
<th>Difference with alternative scenarios</th>
<th>Difference with alternative scenarios</th>
<th>Difference with alternative scenarios</th>
<th>Difference with alternative scenarios</th>
<th>LSD a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>DD-zero</td>
<td>IH-zero</td>
<td>HHD-zero</td>
<td>ALL-half</td>
<td>LSD a</td>
<td></td>
</tr>
<tr>
<td><strong>Sales:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>686,5</td>
<td>3,18</td>
<td>14,69</td>
<td>4,63</td>
<td>11,93</td>
<td>13,80</td>
<td>0,29</td>
<td></td>
</tr>
<tr>
<td>Cows</td>
<td>37,3</td>
<td>0,96</td>
<td>-0,26</td>
<td>-0,55</td>
<td>-2,10</td>
<td>-1,32</td>
<td>0,08</td>
<td></td>
</tr>
<tr>
<td>Heifers</td>
<td>11,3</td>
<td>3,17</td>
<td>5,41</td>
<td>2,19</td>
<td>11,18</td>
<td>8,25</td>
<td>0,28</td>
<td></td>
</tr>
<tr>
<td>Calves</td>
<td>11,4</td>
<td>0,19</td>
<td>0,03</td>
<td>0,04</td>
<td>-0,09</td>
<td>-0,01</td>
<td>0,02</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>746,5</td>
<td>4,74</td>
<td>19,87</td>
<td>6,31</td>
<td>20,93</td>
<td>20,72</td>
<td>0,26</td>
<td></td>
</tr>
<tr>
<td><strong>Purchase:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed, cows</td>
<td>252,6</td>
<td>0,79</td>
<td>4,90</td>
<td>1,29</td>
<td>3,52</td>
<td>4,29</td>
<td>0,07</td>
<td></td>
</tr>
<tr>
<td>Feed, heifers</td>
<td>86,9</td>
<td>2,26</td>
<td>0,31</td>
<td>0,32</td>
<td>-0,74</td>
<td>-0,04</td>
<td>0,18</td>
<td></td>
</tr>
<tr>
<td>Treatments</td>
<td>26,6</td>
<td>0,31</td>
<td>-11,12</td>
<td>-0,57</td>
<td>-6,80</td>
<td>-8,11</td>
<td>0,03</td>
<td></td>
</tr>
<tr>
<td>Insemination</td>
<td>10,6</td>
<td>0,16</td>
<td>-0,12</td>
<td>-0,13</td>
<td>-0,32</td>
<td>-0,25</td>
<td>0,01</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous*</td>
<td>35,6</td>
<td>0,51</td>
<td>0,08</td>
<td>0,07</td>
<td>-0,16</td>
<td>0,00</td>
<td>0,04</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>412,4</td>
<td>3,29</td>
<td>-5,94</td>
<td>0,99</td>
<td>-4,50</td>
<td>-4,12</td>
<td>0,26</td>
<td></td>
</tr>
<tr>
<td><strong>Margin:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total, x1000 €</td>
<td>334,1</td>
<td>2,81</td>
<td>25,82</td>
<td>5,32</td>
<td>25,43</td>
<td>24,84</td>
<td>0,3</td>
<td></td>
</tr>
<tr>
<td>Per cow-year, €</td>
<td>1688</td>
<td>13,8</td>
<td>129,1</td>
<td>26,6</td>
<td>125,5</td>
<td>123,5</td>
<td>1,2</td>
<td></td>
</tr>
<tr>
<td>Per kg ECM, €</td>
<td>0,185</td>
<td>0,0011</td>
<td>0,010</td>
<td>0,002</td>
<td>0,011</td>
<td>0,010</td>
<td>0,0001</td>
<td></td>
</tr>
</tbody>
</table>

a LSD = Least significant difference (p<0,05)

* other costs cows, other costs heifers, interest on operating capital
Table 6

Mean and standard deviation (sd) of annual technical and economic effects in a scenario with a high risk of all lameness causing diseases in a herd with poor reproduction and the mean differences with alternative scenarios where DD, IH and HHD risk are set to zero and all three risks are halved.

<table>
<thead>
<tr>
<th></th>
<th>High risk</th>
<th>Difference with alternative scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Cow-years</td>
<td>188,2</td>
<td>2,6</td>
</tr>
<tr>
<td>Milk yield, kg (^\dagger) ECM (^a)</td>
<td>8857,2</td>
<td>48,0</td>
</tr>
<tr>
<td>Replacement rate</td>
<td>43,2</td>
<td>1,2</td>
</tr>
<tr>
<td>Calving interval</td>
<td>415,9</td>
<td>1,8</td>
</tr>
<tr>
<td>Bought heifers *</td>
<td>3,9</td>
<td>1,9</td>
</tr>
<tr>
<td>DD cases *</td>
<td>435,0</td>
<td>4,6</td>
</tr>
<tr>
<td>IH cases *</td>
<td>35,1</td>
<td>1,0</td>
</tr>
<tr>
<td>HHD cases *</td>
<td>43,0</td>
<td>1,0</td>
</tr>
<tr>
<td>Margin: Total, x1000 €</td>
<td>302,2</td>
<td>6,84</td>
</tr>
<tr>
<td>Per cow-year, €</td>
<td>1604</td>
<td>17,9</td>
</tr>
<tr>
<td>Per kg ECM, €</td>
<td>0,181</td>
<td>0,0014</td>
</tr>
</tbody>
</table>

\(^a\) ECM = energy corrected milk

\(^b\) LSD = Least significant difference (p<0,05)

\(^\dagger\) per cow-year

* per 100 cow-years
Table 7

Costs (€) per case of digital dermatitis (DD), interdigital hyperplasia (IH) and hoof horn diseases (HHD) and increase in margin per cow-year when halving all disease risks (Half) at a high and low level in a herd with average and poor reproduction

<table>
<thead>
<tr>
<th></th>
<th>Average reproduction</th>
<th>Poor reproduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Risk</td>
<td>Low risk</td>
</tr>
<tr>
<td>DD</td>
<td>31,1</td>
<td>31,9</td>
</tr>
<tr>
<td>IH</td>
<td>66,6</td>
<td>62,0</td>
</tr>
<tr>
<td>HHD</td>
<td>261,4</td>
<td>248,7</td>
</tr>
<tr>
<td>Half</td>
<td>123,5</td>
<td>29,3</td>
</tr>
</tbody>
</table>
Table 8

Change in gross-margin per cow-year (median and standard deviation, SD) as a result of halving disease risks when using 9 different sets of distributions for herds with average and poor reproduction

<table>
<thead>
<tr>
<th>Hyper distribution</th>
<th>Average reproduction</th>
<th>Poor reproduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set</td>
<td>Median</td>
<td>SD</td>
</tr>
<tr>
<td>1</td>
<td>77,7</td>
<td>26,2</td>
</tr>
<tr>
<td>2</td>
<td>59,7</td>
<td>29,8</td>
</tr>
<tr>
<td>3</td>
<td>104,7</td>
<td>26,4</td>
</tr>
<tr>
<td>4</td>
<td>40,6</td>
<td>23,9</td>
</tr>
<tr>
<td>5</td>
<td>118,9</td>
<td>20,7</td>
</tr>
<tr>
<td>6</td>
<td>31,5</td>
<td>22,6</td>
</tr>
<tr>
<td>7</td>
<td>125,2</td>
<td>19,9</td>
</tr>
<tr>
<td>8</td>
<td>29,3</td>
<td>22,1</td>
</tr>
<tr>
<td>9</td>
<td>123,5</td>
<td>20,1</td>
</tr>
</tbody>
</table>