Development of a model to calculate the economic optimal day of insemination in dairy cattle

MSc minor thesis

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Preface

In front of you is my MSc minor thesis in Business Economics at Wageningen University. I decided to do a minor thesis in Business Economics in June 2008. The next step was to choose a subject, but this was not so easy. Many subjects looked nice, but finally I made the decision for this thesis subject. In this thesis I looked at the economic optimal day of insemination in dairy cattle with help of a stochastic and a deterministic model. From the beginning of September 2008 to the end of February 2009 I worked on this thesis. I am content with the result and worked with pleasure on it.

I would like to thank my supervisor Dr. Ir. H. Hogeveen for his support and good remarks. I would like to thank Mr. C. Inchaisri too for his explanation of the original reproduction model.

Saskia Luttikholt
Wageningen, February 2009

Summary

The objective of this thesis was to develop an insemination model to calculate the economic optimal day of insemination in dairy cattle. This model was developed in Excel with @Risk add-in software. The model takes an individual cow with a specific parity, persistency and estimated milk yield as base of the model. Furthermore the ovulation rate, estrus detection rate, conception rate, disease incidence and voluntary waiting period have to be filled in.

The results are based on two different scenarios, an optimal and an average scenario. The optimal scenario represents the best possible values for the above mentioned input parameters. The average scenario stands for an average Dutch dairy farm. The lactation curve is based on Wood's function and varies with persistency and parity of the cow. The model simulates various outputs with these input values. The outputs which are determined are the calving interval, days open, number of inseminations, calves per year and realized milk production. The economic results are calculated to make it possible to compare the results. This is done with the help of the price for milk, calving costs, costs of drying off, price of the calf, costs of insemination and replacement costs. Some diseases are a consequence of calving and for that reason part of the calving costs. For every economic important disease the incidence rate and cost per case are given, which are summed up in total costs per cow.
Also a deterministic model has been made to make the insemination tool available for a larger group of people. The results of the deterministic are more or less similar to the results of the stochastic model. The most remarkable difference is that the voluntary waiting period is replaced by day of detection of estrus. At this point the farmer can decide to inseminate or to wait one ovulation, the results of both decision are given.

The results are split up in the technical and economic results for the optimal and average results. For an average cow on an average farm the calving interval is 393 days with 113 days open with a milk yield corrected for gestation of 7884 kg/year, 1.77 inseminations, 0.94 calves per year and a culling rate of 1%. The economic results are given as an economic loss for the average situation with the optimal situation as reference point. The main losses are due to a lower milk production, which are about 100 euro, the total losses are estimated on 113 euro. A sensitivity analysis has been done to see the influence of the economic parameters and the effect of a larger voluntary waiting period on the economic result. In the deterministic model these results are obtained by waiting one ovulation longer with insemination. The milk price has the largest influence, but also the insemination costs and calving costs are important. The retention pay off and the price of the calf have less influence. The optimal day of insemination for 27 cows that differ in persistency, parity and milk yield is determined. The voluntary waiting period varies from 60 to 120 days and for all cows the shortest voluntary waiting period is preferable. The losses due to a longer voluntary waiting period vary between €0.95 and €2.31 per day. The costs increase with an increasing estimated milk production and parity, but not in time.

No external validation has been done, but validity and creditability are checked by comparing with the most recent statistics from the Dutch Royal Cattle Syndicate. The model is a reduction of reality and only the major factors are taken into account. One factor which is not taken into account is a restriction on a high milk yield at drying off, mainly the case for cows with a high persistency and milk yield. Another factor is the increased reproductive performance for cows with a longer calving interval. Other things are cost of feed, percentage fat and protein in milk and the production effect. But these factors are discussed a lot and their effect on the economic results is not very clear. There are some differences between the stochastic and deterministic model, which are caused by a difference in estimated milk yield and the culling rate. These differences are difficult to prevent, because the way of calculating the output values between the methods is different. It can be concluded that optimal day of insemination, when looking at a voluntary waiting period of 60-120 days, is after a waiting period of 60 days.

Content

1. Introduction

The milk yield on dairy farms has increased from 7671kg per year in 2002 to 8179 kg milk per year in 2007. For several decades this increase in milk yield has been seen. This is possible due to genetic selection for cows with a high milk yield, improved management and better nutrition. It seems to be that this selection on high producing cows influenced the reproduction traits in a negative way (Rauwe, 1998). On dairy farms the reproductive efficiency is an important aspect of the profitability. A relative low reproductive efficiency can reduce the profitability obtained by an increased milk yield.

Many factors influence the reproductive efficiency. Some aspects of the reproductive efficiency are calving interval, oestrus detection and insemination rate. Also the price of for example the calf, insemination and culling are important. In practice short calving intervals are often correlated with a larger profitability on the farm. Nevertheless the calving interval in the herd-book cows has increased from 389 days in 1994 to 413 days in 2007 (NRS, 2008). There can be a couple of reasons for this. The first reason is that high producing cows have, in general, a longer calving interval, show more days open and have a higher insemination rate. This can be to a lower reproductive performance of the cow or due to management decisions of the farmer or a combination of both factors. The second reason is that high-producing herds show an upwards shift in their lactation curve when calving intervals are extended. The herds with the highest milk production have on average longer calving intervals (Amburgh, 1997). Because the above mentioned values are highly correlated with the management practices of the farmer, is it hard to create the right conclusions (Rauw, 1998). Data from the NRS show that there are increasing problems with oestrus detection and fertility. The insemination rate in the average Dutch cow has changed from 1.66 in 1992 to 1.80 in 2002 (NRS, 2008). Oestrus is detected in about 55% of the cases, this means that almost half of the opportunities are missed (Firk, 2002). This will also lead to an extended calving interval, (for an overview of these numbers for a herd-book cow see figure 1).

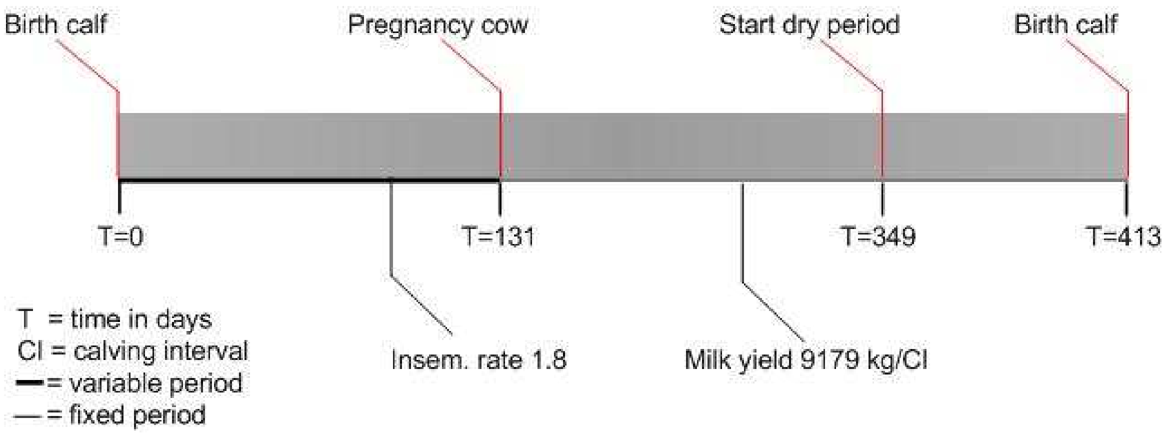

Figure 1. An overview of the calving interval of an average herd-book cow in the Netherlands based on statistics NRS 2008

Often farmers do not pay much attention to the moment of insemination. At the moment oestrus is detected, cows will be inseminated. This is partly due the fact that the optimal moment of insemination is difficult to estimate. Many factors have to be taken in account and there are large differences between cows in a herd. Some factors were can be thought of are the expected milk yield, replacement costs and the persistency. But also diseases which are a consequence of calving are important, because they affect the costs of calving. Another factor where can be thought of is the lactation curve. The lactation curve is influenced by the parity, persistency and the day of conceiving of the cow and also the estimated milk yield will have influence. So it is important to include al major factors in the model, so that it gives a realistic output.

Research on this subject is done in the Netherlands in 1990 by Krabbenborg et. al.. They concluded that a calving interval less than a year is optimal for dairy cows which differ in persistency, age and milk yield. As mentioned before many changes took place, more studies on reproduction, breeding decisions and management are done and opinions are different nowadays. There are also some tools available on the internet that can be used to calculate economic losses due to reproduction problems, but they do not have a scientific basis. Also, several studies on the economic value of pregnancy in dairy cattle are done abroad (Groenendaal, 2003). Since for example management techniques, costs and revenues differ from the Netherlands it is useful to develop a model for the specific situation in the Netherlands.

The objective of this thesis is to develop a model, which can be used to determine the economic optimal day of insemination for an individual dairy cow in the Netherlands.

To achieve the objective of this thesis, some research questions are formulated and need to be answered.

1) What are the most important input values and output values to monitor when you want to determine the optimal moment of insemination?

2) What are the economic losses for an optimal situation compared to an average situation with a voluntary waiting period of 60 days for an average cow on an average dairy farm?

3) What is the optimal moment of insemination for different 'standard' cows?
These 27 standard cows differ in persistency, milk yield and lactation number.

4) Is there a way to make the programme easy accessible and suitable for people who are interested?

2. Material and methods

An insemination model to calculate the economic optimal moment of insemination was developed. This model is based on a Monte-Carlo stochastic-simulation model of Inchaisri et al. (2009) which can be used to estimate the economic consequences of reproductive performance. The model is created in Excel (Microsoft Corporation, Redmond, WA, USA) with @Risk add-in software (Palisade Corporation, Ithaca, NY, USA). The model was changed on various points, but the base stayed the same. The main difference is the change of the input values for the cow, the time steps which are changed from weeks to days and a specific overview for the diseases. In this paragraph the model will be explained.

2.1. Base model

An individual cow has been taken as a basis of the model. The expected yearly milk production, persistency and parity of the cow can be filled in. Furthermore the chance on disease occurrence during the lactation period, the voluntary waiting period, the ovulation rate, the oestrus detection rate and the conception rate can be changed (table 1). The recovery period after the occurrence of a disease is set on 28 days and is a fixed value. The gestation period in days, the first day of ovulation and the time of disease occurrence are estimated from relevant distributions (table 1). With these inputs the model simulated fertility events, which will be explained later on.

Table 1. The input values used in the insemination model

Input	Abbrevation	Chosen values are (between):	Reference
Yearly milk production	MP_{ip}	7000-11000 kg milk/year	CRV (2008)
Gestation period	G_i	Norm(40.00,0.86),Truncate(38.29,41.71)	De Vries (2006)
Persistency	Pers.	Low (-1) or average (0) or high (1)	Dekkers (1998)
Parity of the cow	$P_{1,2,3,4,5,6,7}$	1, 2, 3(or higher)	CRV (2008)
Disease occurrence (%)	Dij	0%-12%	Inchaisri (2009)
Time of disease occ.	j	Uniform (42;98)	Inchaisri (2009)
Recovery period		28 days	Inchaisri (2009)
Voluntary waiting period*	VWP	60-120 days	Experts
The 1ste ovulation (day)	OVU_1		
Parity 1		Lognorm(37.5;35.27, Truncate(7; 35)	Opsomer (1999)
Parity 2 and higher		Lognorm (31.74;21.54, Truncate(7;35)	Opsomer (1999)
Ovulation rate	$POVU_i$	0,95-1,0	Kyle (1992)
Oestrus detection rate	Est	0,55-1,0	Firk (2002)
Conception rate	Con	0,55-1,0	Windig (2005)
Maximum days**		280 days	NRS (2008)
Milk	Mp	€0,12	Huijbs, (2008)
Insemination costs	Cai	€20	NRS (2008)
Price of the calf	Pc	€100	Houben (1994)
Calving costs	Cc	€151,48	-
Drying off		€15,00	Experts
Disease treatments		€59,48	See table 4
Labour		€72	Experts

Retention pay-off	RPO_i		-
Parity 1		-€465,69	Houben (1994)****
Parity 2		-€620,68	" "
Parity 3		-€627,21	" "
Parity 4		-€599,29	" "
Parity 5		-€554,13	" "

* The voluntary waiting period is the period after calving in which the cow won't be inseminated
**This input is the maximum number of days after calving where the cow should be pregnant or else she will be culled.
*** Value is based on costs and revenues of milk
**** Retention pay-off adjusted to more recent prices

The time steps are in days. The maximum number of days can be changed, but is standard set on 280 days. This means that when the cow is not pregnant 280 days after given birth to the calf, the insemination is stopped and finally she will be culled.

The results are based on two different scenarios, an optimal situation and a situation on an average Dutch dairy farm, see table 2. It is tried to represent an average Dutch dairy farm as good as possible. In the optimal situation the ovulation rate, oestrus detection rate and conception rate are set to 1. This means that all these parameters are 100%. The ovulation rate in the average situation is 0.95, as well the oestrus detection rate as the conception rate is 0.55. For both situations an average cow is used with an average persistency, a yearly milk production of 9000 kg in parity 2. The voluntary waiting period in both situations is at least 60 days. Finally the disease incidence differs, in the optimal situations disease did not occur. In the average situations disease occurred with an incidence of 0.11.

Table 2. The values used for an optimal and average reproductive situation

Input	Optimal	Average	Reference
Ovulation rate	1	0.95	(Inchaisri,2009)
Oestrus detection rate	1	0.55	(Firk,2002) (Laporte, 1994)
Conception rate	1	0.55	(Laporte, 1994) (NRS, 2007)
Persistency	Average	Average	(Dekkers, 1998)
Milk production (kg/year)	9000	9000	(NRS, 2008)
Parity	2	2	(NRS, 2008)
Voluntary waiting period (days)	60	60	Arbel (2001)
Disease incidence	0.0	0.11	Laporte (1994)

The model estimates various outputs; day of start insemination, real milk production, calving interval, calves per year, inseminations per year and days open (table 3). For an evaluation of these results the milk price, insemination costs, price of the calf, calving costs and replacement costs are needed (table 1). The milk price is build up from the marginal cost and revenues. The marginal costs taken into account are costs of water, manure, health, breeding costs and feed, the revenues are calves, meat and the fact that the yearly milk quota has to be fulfilled and more cows are needed for that (Huijbs, 2008). The calving costs are build up from the costs of drying off, disease treatment and labour. The parity of the dairy cow has influence on the retention pay-off. The retention pay-off is the present value of the cow less the replacement costs which include the costs of buying and raising a heifer. Finally with these parameters an economic evaluation is made. For a specific cow the difference in the economic results between an optimal situation and the input situation is calculated. These differences in yearly revenue for milk yield and calves, insemination costs, calving costs and culling costs are represented as the 'economic losses'. A positive value means that there are economic losses and a negative value indicates revenue for that parameter.

Table 3. Overview of the output parameters

Output	**Formula**
Day start insemination	-
Real milk production* (kg/year)	total milk production in lactation*365/calving interval
Calving interval (days)	first day gestation +gestation period in days
Calves per year	365/calving interval
Inseminations per year	-
Days open	first day of pregnancy
Milk revenue/year	Milk price (Mp) *∆ real milk production (1)
Revenue calves/year	Price of the calf (Pc) * ∆ calves per year (2)
Insemination costs/year	Insemination cost (Cai) *∆ inseminations per year (3)
Calving costs/year	Calving costs (Cc) * ∆ calves per year (4)
Culling costs/year	Culling costs (RPO) (5)
Net economic loss	
Cow conceives	1+2+3+4
Cow fails to conceive	3 + 5

*Corrected for gestation
** Only when the cow is culled

2.2. Lactation curve

The lactation curve of the cow was calculated using Wood's function (Wood, 1967). The daily milk production was calculated using the expected yearly milk production, parity and the persistency of the individual cow. The persistency can be low, average or high. The lactations curve parameters belonging to the various persistency's of the cows are based on the milk production curves of Canadian Holsteins (Dekkers, 1998). Below the Wood function (formula 1) as used in the model with daily milk yield (MY_{ij}) on a specific day (j) of a cow (i) with parity (P_n) with an expected milk production (MP_{ip}) is given (Inchaisri, 2009). A, B and C are parameters of the Wood function with A and B describing the lactation curve slope and the peak milk yield. Parameter C describes the decrease in milk yield after the peak and is influenced by the parity and the persistency. The original Wood function is adjusted in such a way that it is possible to fill in the expected milk production.

$$MY_{ij} = \begin{cases} \dfrac{(A \times (j/7)^{B} \times e^{-Cp\times(j/7)})_{ij} \times MP_i)}{\sum_{j=1}^{308} (A \times (j/7)^{B} \times e^{-Cp\times(j/7)})_{ij}} \\ i = 1 \\ j = 1,..., \text{day at drying off} \\ A = 1 \\ B = \dfrac{\text{day of peak yield} * C}{7} \\ C = \dfrac{\text{day between peak and end} * Q_{p_n\,pers}}{\text{day of peak yield - day between peak and end}} \\ Qp_1 = 1 * Pers_n \rightarrow Pers_{-1} = -0.0185 \; Pers_0 = -0.0105 \; Pers_1 = -0.0035 \\ Qp_2 = 1.59 * Pers_n \rightarrow Pers_{-1} = -0.0275 \; Pers_0 = -0.0160 \; Pers_1 = -0.0100 \\ Qp_3 = 1.77 * Pers_n \rightarrow Pers_{-1} = -0.0250 \; Pers_0 = -0.0165 \; Pers_1 = -0.0110 \end{cases} \qquad [1]$$

The lactation curve was corrected for pregnancy of the cow (Olori, 1997). This has been done by using formula 2 with MY_{loss} is the loss in milk yield due to gestation and d is the day of gestation. The loss in milk production starts after 35 days of pregnancy. The daily milk yield (MY_{ij}) less the loss due to pregnancy MY_{loss} is the adjusted milk production ($MYadj_{ijd}$).
.

$$\mathrm{MYadj}_{\mathrm{ijd}} = \begin{cases} \mathrm{MY}_{\mathrm{ij}} - \mathrm{MYloss}_{\mathrm{ik}} \\ \mathrm{MYloss}_{\mathrm{ik}} = 0.18[\exp(0.093 \times (d/7)] \\ \mathrm{j} = 1,..., \text{ day of drying off} \\ \mathrm{d} = 35,...,282 \\ \mathrm{i} = 1 \end{cases} \qquad [2]$$

2.3. Diseases

A part of the diseases which occur are a consequence of calving, so these diseases are part of the calving costs. To make a good estimation of these costs, every economic important disease is separately estimated. The economic most important diseases in the Netherlands are milk fever, retained placenta, ketosis, displace abomasums, dystocia, metritis, cystic ovaries and mastitis (table 4). The incidence rates of these diseases are given and also the costs per case. By multiplying them, these two values are combined in a value called average costs per animal. The sum of the average costs is added up by the other calving costs.

Table 4. Overview of the diseases with the incidence, costs per case and average costs per cow

Disease	Incidence in %	Cost per case	Average cost/cow	Reference
Milk fever	1.60	€ 258.00	€ 4.13	Kelton (1998)
Retained placenta	7.40	€ 220.00	€ 16.28	Kelton (1998)
Ketosis	4.90	€ 112.00	€ 5.49	Kelton (1998)
Displ. Abomasums	6.30	€ 220.00	€ 86.00	Kelton (1998)
Dystocia	1.20	€ 200.00	€ 2.40	Kossaibati (1997)
Metritis	7.60	€ 90.00	€ 6.84	Kelton (1998)
Cystic ovaries	9.20	€ 31.00	€ 2.85	Dijkhuizen (1995)
Mastitis *	3.52	€ 217.00	€ 7.63	Huijbs, (2008)
Total			€ 59.48	

* Mastitis as a consequence of calving (Barkema, 1998)

2.4. Reproductive cycle

First day of ovulation (OVU_1) is determined from a lognormal distribution (table 1). This distribution differs between cows in parity 1 and parity 2 and 3 (and higher). The assumption is made that the cow ovulates every 21 days after the first ovulation with a certain probability ($POVU_i$). This probability can be adjusted for every cow. The cow will not ovulate when disease occurred, post partum disorders can delay ovulation with 28 days, these disorders occur with a certain probability (D_{ij}). A disorder did not occur more than once per lactation and the time of occurrence was from a uniform distribution (table 1).

$$
OVU_{ij} = \begin{cases} 0 \rightarrow D_{ij\text{-}n} = 1 \rightarrow n = 0,1,..27 \\ 0 \rightarrow j < OVU1 \\ 0 \rightarrow 1 \subseteq OVU_{ij-1} \cup OVU_{ij-20} \\ \text{discrete}[(1,0),(POVU_i, 1 - POVU_i)] \\ i = 1 \\ j = 1,2,...,280 \end{cases} \quad [3]
$$

The next step was to simulate detection of ovulation (formula 4). Detection of ovulation (Est) was adjusted after peak milk yield at day 42 with an increase in chance on detection with decreasing milk yield. The detection of the first ovulation was considered to be 50% of Est.

$$
EstAdj_{ij} = \begin{cases} 0 \rightarrow OVU_{ij} = 0 \\ 0.50 \times Est \rightarrow j = OVU1 \\ Est \rightarrow OVU_1 < j < 42 \mathit{day}s \\ \left(\dfrac{Est \times MY_{42}}{MY_{ij}} \right) \\ i = 1 \\ j = 1,...,280 \end{cases} \quad [4]
$$

The insemination plan depends on several factors (formula 5). First the cow should be detected in oestrus (ED_{ij}). Next the voluntary waiting period determined if the cow was inseminated. The day of insemination had to be bigger than the voluntary waiting period to inseminate the cow. Also should the day of insemination be smaller than the maximum number of days. This maximum number of days represents the number of days after calving where the cow should be pregnant or else she will be culled.

$$
INS_{ij} = \begin{cases} 0 \rightarrow ED_{ij} = 0 \\ 0 \rightarrow ED_{ij} = 1 \rightarrow j < VWP \\ 1 \rightarrow ED_{ij} = 1 \rightarrow j \geq VWP \\ i = 1 \\ j = 1,...,280 \end{cases} \quad [5]
$$

Insemination of the cow does not guarantee pregnancy. There is a certain chance on pregnancy, which is called the conception rate (Con). The conception rate is adjusted for the parity number and the stage of lactation (formula 6). The length of the gestation period was determined from a normal distribution (table 1).

$$
PCon_{ij} = \begin{cases} 0 \rightarrow INS_{ij} = 0 \\ 0 \rightarrow j < 35 \\ (41.5 - 345 \times 0.6^{(j/7)}) \times \dfrac{Con}{0.37} \rightarrow j \geq 35 \\ i = 1 \\ j = 1,...,280 \end{cases} \quad [6]
$$

2.5. Validation

An internal validation of the model has been done. An important part of this process is already done with making and adjusting the model. The most important problems became clear by then. Furthermore all the variables have been tested by setting them to the lowest, average and highest possible value to see if the data are consistent and credible. The results are also compared with statistics from the Dutch dairy farms, to see of the output is realistic. No external validation has been done because of the absence of suitable data.

2.6. Sensitivity analysis

First a sensitivity analysis for the economic parameters has been done. The parameters used are the price of milk, insemination costs, calving costs, price of the calf and retention pay-off. It has been done to get insight in which parameters are important and have a high influence. Table 5 shows the used values for the sensitivity analysis. It is tried to use values from the practice, so that the outcome is useful.

Table 5. Values used in the sensitivity analysis for the economic parameters

Parameter	Used values in sensitivity analysis are
Milk	€0.05 and €0.25
Insemination costs	€10 and €80
Price of the calf	€20 and €140
Calving costs	€0 and €250
Retention pay-off (parity 2)	-€1000 and €0
Voluntary waiting period	60 days and 120 days

The end goal was to determine the optimal moment of insemination for an individual dairy cow. This has been done by using sensitivity analysis in the programme @RISK. With this analyse it is possible to vary one input and see the effect on the output. In this case the input 'voluntary waiting period' was variable and the economic results were monitored. This has been done for 27 different standard cows. These cows had a low, average or high persistency, were in parity 1, 2 or 3 and had a milk yield of 7000, 9000 or 11000 kg per year. All combinations of these inputs are made, so it was possible to see for these cows by changing the voluntary waiting period, what the optimal day of insemination is.

2.7. Deterministic model

To make the insemination model available for a larger group of people, it was decided to make a deterministic model with use of Excel (Microsoft Corporation, Redmond, WA, USA). This model should generate the same output as the stochastic model. The average values of a Dutch dairy farm (table 2) are also used in the deterministic model. Validation of this deterministic model has been done by comparing with the results of the stochastic model.
There are some differences in the way the results are obtained and this will give different output values. In the deterministic model there is no voluntary waiting period. The voluntary waiting period is changed to a day where the farmer detects oestrus and wants to inseminate. This means automatically that the voluntary waiting period is exceeded. The detection of the first oestrus is therefore 100%. At this point a decision can be made to insemination or to wait until the next ovulation. It is assumed that the cow ovulates again in 21 days. The results of both decisions are given in the model.

3. Results

3.1. Technical results

In this paragraph the technical results for an optimal situation and an average Dutch farm are given, see table 2 for the input parameters. The optimal situation is a situation where the technical parameters are the highest possible level.
The day of first insemination was in the optimal situation on average 71 days after calving. Because the chance on pregnancy after insemination is 100%, the cow is on average pregnant on day 72. Only one insemination is needed to get the cow pregnant. The average calving interval is 351 days; this will lead to 1.04 calves per year. The milk production is estimated on 8722 kg/year and the culling rate is zero. With the inputs for an average situation the average day of first insemination is day 88. Furthermore there are 113 days between calving and pregnancy. The cow is 1.77 times inseminated per year. Also the calving interval will be larger than in the optimal situation, namely 393 days. This gives 0.94 calves per year. The milk production is on average 7883 kg per year and the culling rate is around 1.00 percent. Furthermore it stands out that the variation in almost all parameters increases compared to the optimal situation, see table 6.

Table 6. Technical results (5% and 95% percentiles in parentheses)

Technical parameter	Optimal	Average
Day of first insemination	71 (61,79)	88 (61,136)
Days open	72 (62,80)	113 (64,198)
Calving interval	351 (338,364)	393 (342,476)
MP/cow/year (kg)	8722 (7326,10166)	7883 (5995,9740)
Number of inseminations/year	1.0 (1,1)	1.77 (1,4)
Number of calves/year	1.04 (1,1.08)	0.94 (0.77,1.07)
Culling rate (%)	0.00 (0,0)	1.00 (0,0)

The milk production curve of the cow depends on the estimated milk yield, the parity, the persistency and day of conception. A low persistency gives a curve with a high peak and a large decrease after this peak. A very persistent cow will have a flat curve, but there are also difference in parity. Cows in the first lactation have the most persistent curves, with an increase in lactation number, the lactation curves will become less flat. All the lactation curves are corrected for the day of gestation and the day of drying off. Especially when the cow has a short calving to insemination interval, the milk yield at drying off will be high. In this research the milk yield at drying off varies between 4 and 29 kg per day. Three different lactation curves for a cow with an estimated milk yield of 9000 kg/year and in the second lactation are graphically represented in figure 2. The milk production at drying off is between 6 and 16 kg per day and the total milk yield is between 8944 and 9140 kg per lactation.

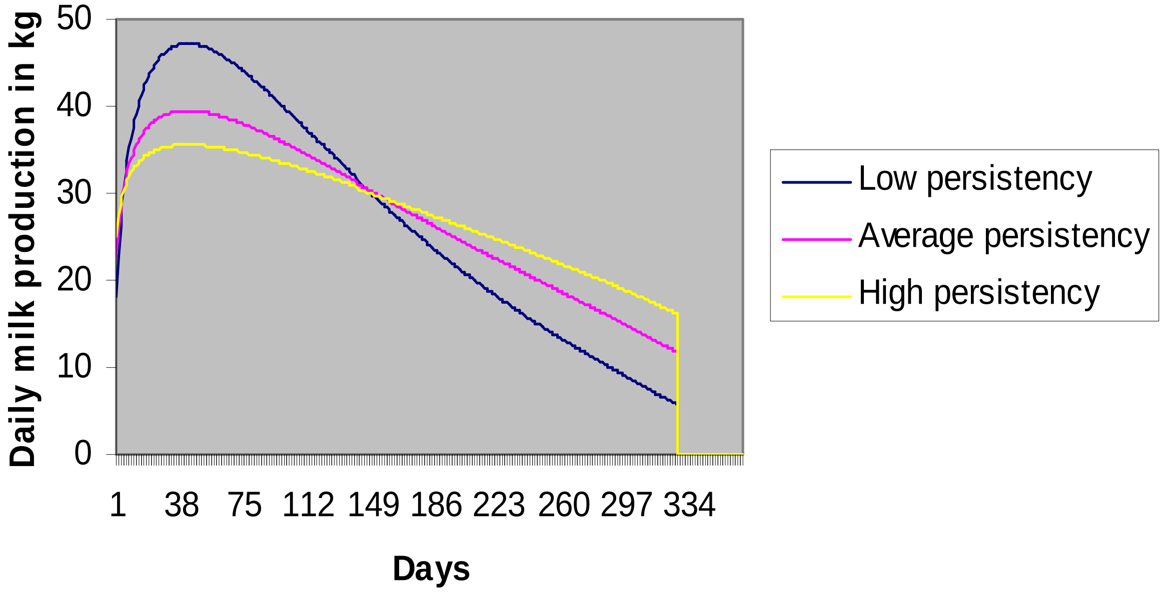

Figure 2. Milk production curves for a cow in parity 2 , conceiving at day 60 with an estimated milk yield per year of 9000 kg for a low, average and high persistency

3.2. Economic results

The economic results are given as the difference between the optimal and average situation, see table 7. The optimal situation is taken as reference point. The total difference between these two situation is 112.71 euro, this means that on average 112.71 euro less is earned compared with an optimal situation. The main difference is due to the milk production, this is almost 100 euro. Other losses are due to less revenue from selling the calf (9.90, more inseminations (11.17) and higher culling costs (6.78). The calving costs are less in an average situation, almost 15 euro.

Table 7. Economic results for an average farm (5% and 95% percentiles in parentheses) compared to an optimal situation.

Economic loss	Average in Euro*
Milk production	99.35 (0, 275)
Calf	9.90 (0, 27)
Insemination	11.17 (-2.31,45.34)
Calving costs	-14.51 (-39.55, 0)
Culling	6.78 (0,0)
Net value	112.71 (0, 311.93)

*Differences in economic value between optimal and average situation with the optimal situation used as reference point

3.3. Sensitivity analysis

First the results of a sensitivity analysis for the economic parameters are given. There is looked at the effect of a single parameter on the economic results, see table 8. In figure 3 is a graphical overview given of the economic losses for the different parameters. The average value is used as a reference point.

The average value of the economic losses is given as every second value of the parameter, which originated from the average scenario. The first parameter looked at is the price of milk. The price was set on 5 cent and 25 cent per kg of milk, it shows that the milk price has a large influence on the economic losses. When the milk price drops with 60% the economic

losses are decreased with about 50%. The opposite is true when the milk price increase 100%; the economic losses are double with 50%.
The insemination costs have less influence, the insemination costs are between 10 and 80 euro with 20 euro as average. This results in economic losses of respectively €110 and €144 with €113 as average. The next parameter is price of the calf. The price of the calf is increased with 40% and decreased with 80% to see the effect on the economic losses. The economic losses change only a bit, with respectively 114 and 104 euro as estimated for both situations. With enlarging the calving costs with 70% the economic losses decrease with 18 euro. The calving costs are also set on 0 euro, this increases the economic losses to 134 euro. The last parameter looked at is the retention pay off, which associates with the culling rate. Not much difference is seen by changing this value, due to the low culling rate.

Table 8. The economic losses for different values of the economic parameters (5% and 95% between parentheses)

Parameter	Value	Economic losses in euro*
	€0.05	55 (0, 161)
Milk price	€0.12	113 (0, 309)
	€0.25	222 (0,630)
	€10	110 (0,309)
Insemination cost	€20	113 (0, 309)
	€80	149 (0, 434)
	€20	104 (0, 298)
Price of calf	€100	113 (0, 309)
	€140	121 (0, 331)
	€0	134 (0, 356)
Calving costs	€151	113 (0, 309)
	€250	103 (0, 287)
	-€1000	119 (0, 323)
RPO	-€621	113 (0, 309)
	€0	106 (0, 307)

* Economic losses for the average situation compared to an optimal situation

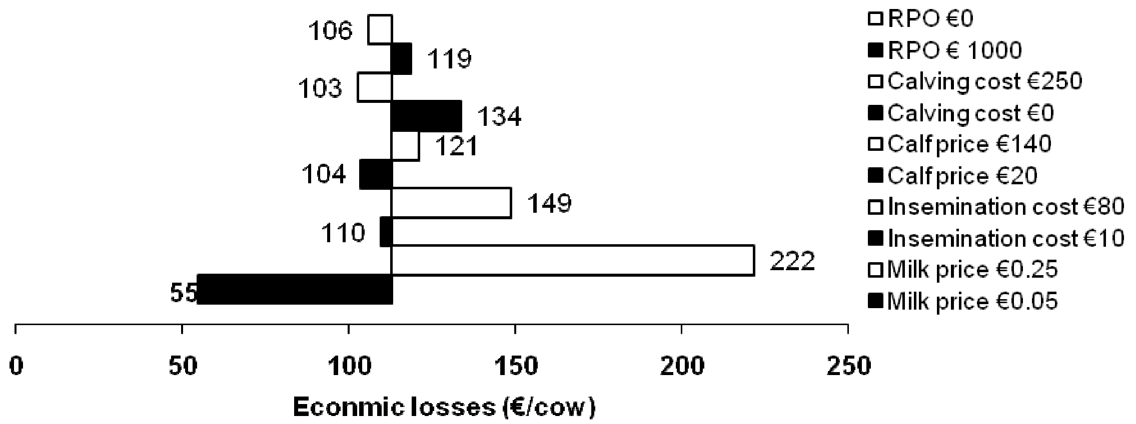

Figure 3. The economic losses for different values of the economic parameters with 113 euro for the average values as reference point

The optimal day of insemination is calculated for an average cow on an average farm. This is done with an advanced sensitivity analysis in @Risk. The parameters inputs are of an average farm from an average cow, as described in table 2. The voluntary waiting period varied between 60 and 120 days and the economic result is monitored.

Results are given for different cows on an average farm as described in table 2. The milk production is split up in three levels, namely 7000, 9000 and 11000 kg/year. Further distinguish has been made between a low, average and high persistency. The parity is also distributed in three levels, namely parity 1, 2 and 3 and higher. The results are given as the difference in Euro between a voluntary waiting period of 60 versus 90 and 120 days, a positive value means an economic loss.

In all scenarios the optimal voluntary waiting period was 60 days. From that point the economic losses increases slightly with an increasing waiting period, for both voluntary waiting period 60 days is used as reference. The economic losses are between €31.84 and €69.29 for a waiting period of 90 days. When this is increased to 120 days the economic losses are between €64.39 and €139.40. As can be seen in table 9,10 and 11 in almost all cases the economic losses grow with a higher estimated milk yield and higher parity. The differences due to persistency are relatively small. Cows with a higher persistency give most of the time slightly better results.

Table 9. Results for cows with an estimated milk yield of 7000 with a different persistency and parity

Persistency	Parity	Economic losses (€) with a voluntary waiting period (in days) of 90	120
	1	31,84	65,45
Low	2	34,02	69,88
	3+	40,67	81,24
	1	29,46	64,39
Average	2	32,69	73,23
	3+	40,76	79,24
	1	28,42	61,50
High	2	33,93	73,47
	3+	38,81	75,87

*The optimal situation is used as reference point

Table 10. Results for cows with an estimated milk yield of 9000 with a different persistency and parity

Persistency	Parity	Economic losses (€) with a voluntary waiting period (in days) of 90	120
	1	41,60	87,42
Low	2	48,85	101,46
	3+	45,55	100,56
	1	41,82	83,67
Average	2	47,00	93,53
	3+	49,19	98,99
	1	39,84	83,05
High	2	47,37	99,33
	3+	55,30	108,56

*The optimal situation is used as reference point

Table 11. Results for cows with an estimated milk yield of 11000 with a different persistency and parity

Persistency	Parity	Economic losses (€) with a voluntary waiting period (in days) of	
		90	**120**
	1	48,75	99,16
Low	2	58,66	132,10
	3+	69,29	139,40
	1	46,72	104,48
Average	2	53,54	117,26
	3+	62,94	133,13
	1	50,78	111,67
High	2	61,94	127,77
	3+	63,17	124,81

*The optimal situation is used as reference point

3.4. Deterministic model

The aim was to derive the same results with the deterministic model as with the stochastic model. Small differences are difficult to prevent and will be allowed. Also in this model the input values of an average cow on an average cow will be used. As the deterministic model is made in Excel without the @Risk add-in. For this reason it is decided to give an optimal situation, an average situation and an average situation where is decided to inseminate one ovulation later.
The first day of pregnancy in the optimal situation is equal to the day of oestrus detection. For an average situation the first day of pregnancy is estimated at 105 days and when waiting one ovulation the first day will become 125 days after calving. There are 1.07 inseminations per year in an optimal situation, this is due the fact that the calving interval is less than a year. In this situation the number of calves per year is equal to the number of inseminations. The calving interval is estimated on 342 days. In an average situation the number of inseminations increases to 1.71, but by waiting one ovulation the insemination will decrease to 1.63. The calving interval increases by delaying the first day of insemination, for an average farm it will become 387 days and when the farmer waits one more ovulation it is 407 days. As a consequence the number of calves per year drops respectively to 0.94 and 0.90. The culling rate is in optimal situation zero, for an average situation 2.36% of the cows will be culled due to reproductive problems and by waiting one ovulation it will increase to 3.31%.
The milk production during lactation will increase by extending the calving interval. But due the fact that the highest amount of milk yield is reached in the first weeks of the lactation the average milk production per year will decrease with an increasing calving interval. In this example the milk production is 8865 kg/year in an optimal situation, 8544 kg/year for an average and 8384 kg/year in when delaying insemination.

Table 12. Technical results of the deterministic model

Results per year	Optimal	Average	Wait one ovulation
First day of pregnancy	60	105	125
Inseminations per year	1,07	1,71	1,63
Calves per year	1,07	0,94	0,90
Calving interval	342	387	407
Culling rate	0,00%	2,36%	3,31%
Milk yield in kg/year*	8865	8544	8384
Milk yield in kg day of drying off	15	12	11

* Corrected for gestation

The economic losses in the deterministic model are given for the average situation compared to the optimal situation and for waiting one ovulation compared to the optimal situation. The milk production account for the highest losses, which are about €40 and €60. The calving cost reduce the economic losses with €18 and €25. The chance on culling increases with waiting one ovulation and this give an average loss of €20.52 in this scenario. These costs are in the average scenario lower, namely €14.62. The costs of insemination are €12.90 in the average situation and by waiting one ovulation these costs will drop slightly to €11.30. The economic losses for the calf are €12.50 in the average situation and €17 when the farmer decided to wait one ovulation. When all these costs are added up the economic losses in the average scenario and waiting one ovulation are respectively €60 and €80, see table 13.

Table 13. Economic losses on an average Dutch farm compared with an optimal situation

Economic losses (€)*	Average	Wait one ovulation
Milk production	€ 38.45	€ 57.71
Calf	€ 12.50	€ 16.99
Insemination	€ 12.92	€ 11.29
Calving costs	-€ 18.31	-€ 24.89
Culling	€ 14.62	€20.52
Net value	€ 60.18	€ 81.62

*The optimal situation is used as reference point

The milk yield at drying off is also an important value for most farmers. For that reason for the 27 ‘standard’ cows the yield at drying off is given in table 14. It is assumed that the cows are seen in estrus on 60 days after calving. There are large differences between the cows, an especially the cows in the first lactation will have a high yield at drying off. Furthermore delaying insemination with one ovulation will drop this yield about 1 kg, which is just a small proportion.

Table 14. The milk yield per day at drying off for 27 'standard' cows

Persistency	Parity	Milk production per year	Yield at drying off in kg
	1	7000	11
Low	2	7000	4
	3+	7000	4
	1	7000	14
Average	2	7000	8
	3+	7000	7
	1	7000	17
High	2	7000	12
	3+	7000	10
	1	9000	15
Low	2	9000	6
	3+	9000	6
	1	9000	19
Average	2	9000	12
	3+	9000	10
	1	9000	23
High	2	9000	16
	3+	9000	14
	1	11000	19
Low	2	11000	8
	3+	11000	8
	1	11000	24
Average	2	11000	15
	3+	11000	13
	1	11000	29
High	2	11000	20
	3+	11000	18

4. Discussion

4.1. In general

No external validation has been done, because data was not available. To check for the validity and credibility of the model the output data are compared with recent statistics from the Dutch Royal Cattle Syndicate (NRS,2008). The statistics for the year 2007 report an average calving interval of 415 and 420 days with an insemination number of 1.8 in 2002 (no recent data available). The interval between calving and the first insemination is about 103 days. The percentage of correct mating is reported on 49% in 2002 (recent data not available), (NRS, 2008). These statistics are close to the estimates for the average situation. A difference is seen in the interval between calving and the first insemination, but this can be explained by the voluntary waiting period. This voluntary waiting period is set on 60 days, but in practice this period will differ per cow. For example in case of disease short after calving, the cow will maybe need a longer recovery period and therefore it is decided to delay insemination. So in practice the voluntary waiting period will differ and will be on average a bit longer than 60 days.

The optimal situation is used as a reference for the average situation; however the optimal situation will never exist in practice. The optimal situation as used in this model has an ovulation rate, detection rate and conception rate of 100%, which are the highest possible results, but not realistic. The economic losses are represented as the difference between the optimal and average situation, therefore you get the largest possible differences. There should not too much value be attached to the exact amount in euro, because the optimal situation can never be realized. It gives an indication of the maximum improvement which can be obtained. It can be used to see which results can be obtained by improving specific parameters and which parameters have high influence.

The model is a reduction of reality, which means that not all factors can be taken in account. We tried to put the major factors in the model. A factor which is not taken in the model is that extending the calving interval can improve the reproductive performance in the next lactation (Larsson, 2000). In the article of Larsson cows with a 12 month and a 15 month calving interval are compared on reproductive performance. Concluded is that cows with a 15 month calving interval need fewer inseminations and are less often culled for reproductive reasons. However it can also have a negative effect on the detection of ovulation and a higher risk on cystic ovaries.

Another factor is the high milk yield at drying off, which mainly applies for high persistent cows. The risk of mastitis increases when the cow is dried off at milk yield of more than 10 kg (Larsson, 2000). For that reason farmers use often a preventive antibiotic treatment, which is included in the model as the costs for drying off. An extended calving interval decreases the milk yield at drying off, which can save costs of the preventive antibiotic treatment. But the disadvantage of this extended calving interval will be the lower average yield per day and this gives less revenue. Only high persistent cows in the first lactation are able to remain their average yield per day for a long(er) period. In table 14 the milk yield at drying off is given for the different standard cows, the milk yield at drying is quit high for the cows in first lactation with a high persistency. It will be difficult to dry off these cows with such a high milk yield and it can give problems. It can be decided to include a restriction on maximum yield at drying off in the model, to predict drying off with a high milk yield. The economic losses estimated in that case will be high, but not realistic, because decreasing the calving interval will not be possible.

High persistent cows with a high milk production are often in demand by the farmer. When the calving interval is extended less progeny of this cow is available per year. So there is a 'genetic loss', which is not accounted for. However the value for a calf can be changed, it is standard set on 100 euro. When more importance is attached to the calf this value can be set on a higher level.

Other adjustment factors for the model can be the percentage fat and protein in milk and the production effect. The economic losses received by a longer calving interval are reduced by these effects. The costs of feed is accounted for by adjusting the milk price. The cow needs less qualitative feed with a lower average milk production because less energy is required The percentage fat and protein in milk drop until 2 to 3 months after calving, they increase gradually after this period. Milk in the period contains in proportion to the first months more fat and protein, which will increase the price. The last factor is the production effect, with a longer calving interval and more days open the milk yield in next lactation will increase a bit (Krabbenborg, 1990). In this model only the effect for a single lactation is described, so this effect is not included.

There is not much information available on the persistency of dairy cows, although this is an important aspect in practice for determining the moment of insemination. The lactation curves used in this model are based on an article of Dekkers (1998). In this article the lactation curves are based on empirical results on Canadian Holsteins. For these Canadian Holsteins is looked at the parity and persistency and subsequently lactation parameters are estimated. For the Dutch dairy cow no specific information about lactation curves is available. But the dairy cow population in Canada and the Netherlands show high similarity, the Canadian Holstein originates from the Dutch Holstein. So the lactation curves will not differ tremendously and give good estimations.

The sensitivity analyses for the economic parameters give an indication of the influence they have on the economic results. The milk price has the highest influence on the economic results of the model, which seems logical because the main difference between the two situations is the milk production. For this sensitivity analysis is looked at an average cow with an average persistency. The influence of the milk price will be smaller when the persistency of the cow is high. The insemination costs differ a lot in practice, so in the sensitivity analysis the insemination costs have a wide range from 10 to 80 euro. Especially when the farmer uses semen of an expensive bull the amount inseminations needed is important to reduce the economic losses. The price of the calf and the retention pay off do not influence the economic losses very much. The calving costs are also an important factor. The difference between the optimal and average situation will become smaller with increasing calving costs. It can be concluded that it is important to look carefully at the economic parameter and fill in the right values for the specific situation or else wrong estimates will be a consequence.

The economic losses simulated with the sensitivity analysis differ with each simulation, due to a relatively low amount of iterations. The sensitivity analysis presented in this thesis give an indication, but will be different for each scenario with each simulation. When the amount of iteration is set on a larger amount the results of the sensitivity analysis will become more and more the same.

Results of the sensitivity analysis show cost of 1 to 2 euro per day of delaying start of insemination from 60 to 90 days. The lowest costs are for a cow in parity 1, with a high persistency and an estimated milk yield of 7000. The costs per day for this particular cow are €0.95. The highest costs are for a cow in parity 3 with a low persistency and an estimated milk yield of 11000, the costs are €2.31per day. There are large differences between different cows, which are mainly consequences of the differences in the lactation curves. In the TOM-model (Krabbenborg, 1990) the costs of a calving interval of 13 months for an average cow with an milk yield of 7000 kg/year was estimated on €0.90. In this model the costs per day for this cow are €1.09. Other studies reported values of €0.06-1.03 (Groenendaal, 2003), €0.44-0.81 (Inchaisri, 2009) and €0.10-0.71 (Schmidt, 1989). It is

difficult to compare these values, because every article uses different input and output values to calculate the costs of days open, the values differ per country and furthermore costs vary in time. But the main differences between the model used in this thesis and the other models can be explained by the relative high estimates of the milk production. The results are comparable when looked at a milk production of 7000 kg per year, but with increasing milk production the differences are also increasing.
Delaying insemination till 120 days gives about the same loss every day, so the costs increase roughly with the same amount every day. Sensitivity analyses show that losses per day are bigger with an increasing milk yield. In absolute term there is a bigger decrease in milk yield per day, which gives higher losses.

The input values in the model are based on different sources, it is tried to use as current data as possible preferably from the Netherlands. This was difficult, because not much scientific data for these parameters is available. For example not all veterinary treatments by dairy cows in the Netherlands are recorded, in contradiction to a country as Sweden. Information about the input parameters is often based on studies in foreigner herds. Another issue is that used studies are not always recent. But it is assumed that the used data is comparable. It seems that this assumption is right, because the output parameters agree to a large extent with statistics from the Dutch Royal Cattle Syndicate.

4.2. Differences between deterministic and stochastic model

There are differences between the output values of the deterministic and stochastic model. First the technical output for an average situation is compared. Mainly the milk production differs substantial, with almost 700 kg/year. This difference can partly be explained by the way the milk production is estimated. In the deterministic model the milk yield is estimated on base of day of pregnancy, parity and persistency of a specific cow. In the deterministic model is no variation in the first day of pregnancy, because one average value is used. In the stochastic model the day of pregnancy differs per iteration and is estimated from a uniform distribution. The results for number of day's open, calving interval, culling rate, inseminations and calves per year are comparable. The values for the stochastic model differ per simulation, for the above mentioned results 1000 iterations are done. This number of iterations is not enough to get every simulation exactly the same results, but more iteration was not possible due to a relatively slow computer.

4.3. Deterministic model

In the deterministic model is looked to an optimal, average and waiting one ovulation situation. This is done for an average cow on an average farm (table 2). Waiting one ovulation, which can be compared to extending the voluntary waiting period with 21 days, costs €1.02 per day. For the same cow in the stochastic model these costs are €1.57 per day, there is a difference of €0.50, which is quit a lot. It is mainly caused by the difference in estimated yearly milk production.

The deterministic model is made especially for farmers and their advisors, so that it is easier for them to make a decision about the right moment of insemination. If the model is really useful in practice is doubtable, because the advice in almost every case will be to inseminate and not to wait one ovulation. But this model can be used to see the predicted values and see the milk yield at drying off.

5. Conclusion

The stochastic model is used to estimate technical parameters for an average Dutch dairy farm. The day of first insemination is 88, with 1.77 inseminations per year, this results in 113 days open. The calving interval will be, on average, 393 days, so there will be 0.94 calves per year born. The milk yield is estimated on 7883 kg milk per cow per year with a chance on culling of 1%. The estimated technical are comparable to statistics for the Dutch dairy sector, so the model gives good estimates for the technical parameters and will be useful.

The economic results for an average cow on an average farm for an optimal situation are compared to an average situation. The difference between these two situations is 113 euro. The main losses are due to a lower average milk production per day in the average situation. The absolute amount of these losses is not very useful because there is compared with an optimal situation, but this optimal situation can never exist in practice. So the largest possible economic losses are estimated but this amount of improvement can never be realised. In the deterministic model is also looked at the difference between insemination at the moment ovulation is detected or waiting one ovulation. The differences between these two scenario's are realistic and useful. For an average farm with detection of ovulation at day 60 this difference is around 52 euro. Delaying insemination with one ovulation will cost the farmer 52 euro for an average cow, this is quite a lot. It can be concluded that the right moment of insemination can save the farmer money and make the farm more profitable.

The most sensitive economic parameters are the milk price, the insemination costs and the calving costs. The price of the calf and the retention pay off have a low influence on the economic losses. A sensitivity analysis for the voluntary waiting period from 60 to 120 days for 27 different standard cows has been done. The economic losses of these voluntary waiting periods are compared and the optimal waiting period is in almost all scenarios 60 days. For cows in first lactation and a high persistency the costs of delaying insemination with different estimated milk production levels are in most cases lowest. Furthermore it can be concluded that large difference exist between cows and different input values. So it is useful to make calculations for each individual cow.

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Appendix

An example of the deterministic model

Invoer

De blauwe getallen kunnen aangepast worden naar u eigen bedrijfsresulaten en per individuele koe.
De weergegeven getallen zjin gebaseerd op landelijke gemiddelden.

KOE	
melkgifte in kg (jaarlijks)	9000
duur van de dracht in dagen	282
tijd tussen ovulaties	21
persistentie (laag (0), gemiddeld (1), hoog (2)	1
lactatienummer	2
aantal dagen voor afkalven droog gezet	60
dracht van de koe binnen aantal dagen	280

BEDRIJF	
percentage zieke dieren	11,00%
kans op ovulatie	95,00%
kans op detectie	55,00%
inseminatie	1
kans op bevruchting	55,00%

ZIEKTES	% Zieke dieren	Kosten per ziektegeval	Gemiddelde kosten per koe
Melkziekte	1,60%	€ 258,00	€ 4,13
Niet afkomen nageboorte	7,40%	€ 220,00	€ 16,28
Slepende melkziekte	4,90%	€ 112,00	€ 5,49
Lebmaagverdraaiing	6,30%	€ 220,00	€ 13,86
Abnormaal baringsproces (dystocia)	1,20%	€ 200,00	€ 2,40
Baarmoederontsteking (chronisch)	7,60%	€ 90,00	€ 6,84
Cysteuze ovaria	9,20%	€ 31,00	€ 2,85
Mastitis (als gevolg van afkalven)	3,52%	€ 217,00	€ 7,63

PRIJZEN		
melkopbrengst/kg		0,12
inseminatiekosten		20,00
afkalverkosten		146,48
	arbeid	*72,00*
	ziektebehandeling	*59,48*
	droogstand	*15,00*
opbrengst kalf		100,00
vervangingskosten koe		-620,68
	lactatie 1	*465,69*
	lactatie 2	*620,68*
	lactatie 3	*627,21*
	lactatie 4	*599,29*
	lactatie 5	*554,13*

INSEMINATIE	
aantal dagen na afkalveren tochtig gezien	60

Resultaten

Kengetallen per jaar	**optimaal**	**gemiddeld**	**1 ovulatie wachten**
eerste dag van dracht	60	105	125
gemiddeld aantal inseminaties	1,07	1,71	1,63
aantal kalveren	1,07	0,94	0,90
tussenkalftijd in dagen	342	387	407
kans op afvoer in procenten	0,00%	2,36%	3,31%
melkproductie in kg	8865	8544	8384
melkproductie in kg op dag van droogzetten	15	12	11
Economische verliezen			
Verschil totaal	€ 0,00	€ 60,18	€ 81,62
Verschil melkopbrengst (€)	€ 0,00	€ 38,45	€ 57,71
Verschil opbrengst kalveren (€)	€ 0,00	€ 12,50	€ 16,99
Verschil inseminatiekosten (€)	€ 0,00	€ 12,92	€ 11,29
Verschil afkalfkosten (€)	€ 0,00	-€ 18,31	-€ 24,89
Verschil vervangingskosten (€)	€ 0,00	€ 14,62	€ 20,52