Economic analysis of the De Laval activity meter system for heat detection

- A case study on farm level

Per Larsson

SLU, Department of Economics
Degree Thesis in Business Administration

D-level, 30 ECTS credits

ISSN 1401-4084
ISRN SLU-EKON-EX-No497--SE

Thesis 497
Uppsala, 2007

Economic analysis of the De Laval activity meter system for heat detection

- A case study on farm level

Lönsamhetsanalys av DeLavals aktivitetsmätarsystem för brunstpassning

-En fallstudie på gårdsnivå

Per Larsson

Supervisor: Hans Andersson

Acknowledgements

The present thesis is written as a master thesis on the Swedish University of Agriculture Science (SLU), Department of economics. It aims to analyze the economic consequences of introducing automated estrus detection on dairy farms. The work with the thesis was carried out as a partnership between SLU and DeLaval international during September 2006 until March 2007.

The time from the beginning of September until now has been a very challenging part of my life. Carrying out the work with the thesis has been as challenging as instructive, both on an educational and a personal level. The work with the thesis has been supported by a number of persons to whom I would like to devote special thanks.

First and foremost I would like to thank my supervisor Hans Andersson, Swedish University of Agriculture Science, Department of Economics. Hans´ great enthusiasm and knowledge has helped me carry out the project. His support has been a source of self confidence when things have been difficult. I would also like to thank Axel Elfgren, DeLaval International, for his support. Axel´s support has been encouraging and helpful as obstacles have appeared. His devotion has illuminated the importance and relevance of the project.

Along the way many persons have been giving useful input to the project and I thank you all for your help. I would like to give a special thanks to Rolf Spörndly, Swedish University of Agriculture Science, Department of Animal Nutrition and Management. Rolf has devoted important time for feed cost calculation, contributing greatly to the results. Among all persons that have helped me I would also like to mention Hans Gustavsson, Swedish Dairy Association, Jan Bertilsson, Swedish University of Agriculture Science and Ann Lindberg, Swedish Dairy Association. Special thanks are also devoted to the DeLaval staff that has helped me and their customers for their contribution to the thesis. You have been most helpful!

Finally a special thanks to Anders Fagerberg who established contact with DeLaval and set me up with this project. The thesis has been a great way to end the wonderful time as a student at the Swedish University of agriculture. The work with the thesis has made me evolve personally and has made me ready to face new challenges with self confidence and determination.

Per Larsson
Uppsala
March, 2007

Abstract

During the last centuries dairy cow breeding has strived to increase milk yield resulting in a dairy cow that produces large quantities of milk. However, high milk yield has been shown to be correlated with decreased reproductive performance (Nebel & McGilliard; 1993). The problem with low fertility among dairy cows has become one of the more costly problems for the dairy industry as of today.

Low fertility causes a number of problems that affect herd profitability. Replacement and calving interval are two measures used to describe dairy herd performance. The maximum milk yield and net farm income is associated with a calving interval of 12 – 13 months (Hollman. 1984). The replacement rate also affects the economic result of the dairy herd. Jagannatha et al (1999) calculate the optimal replacement rate to 20%. However, low fertility tends to increase the calving interval and the number of cows culled increases due to infertility.

The activity meter system provides a management tool that facilitates the detection of cows in heat and provides information that helps to determine the most suitable time of insemination. The objective of this thesis is to evaluate the economic impact of an automated estrus detection system on the dairy farm. The study analyses the impact of improved pregnancy rate on replacement, milk yield, feed costs, breeding costs and the number of calves born. These parameters in combination affect net farm income associated with the introduction of activity metering.

In order to evaluate the consequences of activity metering a simulation model has been developed. The model is a modified waiting line simulation model where pregnancy rate determines the time each cow has to wait for a subsequent insemination ultimately leading to pregnancy. The pregnancy rate is a stochastic parameter with a uniform distribution. If a cow does not become pregnant after a number of inseminations she is culled due to infertility. Based on the pregnancy rate the model calculates the calving interval for each cow and creates an average herd calving interval. Based on the individual calving interval an average daily milk yield is calculated for the herd. Daily average herd milk yield is matched with the corresponding cost of the feed mix.

Based on farm visits and international dairy statistics two case farms have been identified. The first farm is situated in Northern Italy. It is managed as a typical Western European dairy farm. The production is highly specialized and cows do not graze on pasture. Herd size is 400 cows. The other farm is situated in Southwest Great Britain. This farm is characterized as a less intensive operation with a smaller herd, 150 cows. These cows produce a lower annual milk yield compared to the Italian herd. The herd is fed on pasture only to a small extent.

The simulation is carried out by comparing the net revenues of the farm, based on the parameters mentioned, before and after the introduction of the activity metering system. The difference in net revenue between the two cases is the annual net revenue of the activity meter investment. The simulation reveals a positive net revenue in all cases when activity metering is used. The net revenue per cow and year of the investment ranges from 70 to 251 € for the Italian farm and 8 to 178 € for the U.K. farm. The economic impact of the system is more pronounced for the Italian farm. The result change as the initial reproductive performance of the diary herd is improved. If management is characterized by good skills, resulting in a relatively high pregnancy rate prior to introducing the system, the economic impact of the system is not as high, compared to a situation with less skilled management. However, in all cases the simulations display a positive gain in net revenue from using automated estrus detection.

Milk yield, feed cost and replacement rate have the most pronounced impacts on the result. Changes in these parameters account for the larger share of the net revenue of the system. Consequently, initial reproductive performance and the ability of the system to facilitate improvements in reproductive management are of critical importance to the result.

Key terms: Fertility, Dairy Cow, Activity Metering, Calving Interval

Sammanfattning

De senaste decenniernas avelsarbete inom mjölkproduktionen har bland annat syftat till att öka mjölkavkastningen, vilket har resulterat i en mjölkko som producerar stora mängder mjölk. Hög mjölkavkastning har dock visat sig korrelera med försämrad fertilitet (Nebel & McGilliard; 1993). Låg fertilitet har därför blivit ett av de mer kostsamma problemen i modern mjölkproduktion.

Infertilitet förorsakar en rad problem med negativ effekt på lönsamheten. Kalvningsintervall och utslagning är viktiga parametrar som påverkar mjölkproduktionen i en besättning. Mjölkavkastningen och det ekonomiska resultatet påverkas av kalvningsintervallet vilket innebär att det bästa resultatet erhålles vid ett intervall på 12 till 13 månader. (Hollman; 1984). Utslagsprocenten har även stor påverkan på resultatet. Jagannatha m fl (1999) beräknar den optimala utslagsprocenten till 20%. Låg fertilitet tenderar dock att öka både kalvningsintervallets längd och utslagsprocenten då kor som inte blir dräktiga måste slås ut.

Aktivitetsmätarsystemet är ett exempel på ett informationssystem som syftar till att effektivisera mjölkproduktionen. Systemet upptäcker brunster och ger ett beslutsunderlag avseende lämplig tidpunkt för inseminering av en enskild ko. Syftet med denna uppsats är att utvärdera de ekonomiska konsekvenserna av att introducera ett aktivitetsmätarsystem på mjölkgårdar. Studien avser att analysera hur ökad effektivitet i reproduktionsarbetet påverkar utslagsprocent, mjölkavkastning, foderkostnad, reproduktionskostnader och antalet kalvar. Genom en förändring i dessa parametrar analyseras förändring i mjölkföretagets årliga vinst till följd av introduktion av aktivitetsmätarsystemet.

En stokastisk simuleringsmodell har utvecklats. Modellen kan betraktas som en modifierad kösimuleringsmodell där reproduktionseffektiviteten avgör hur lång tid det dröjer innan varje ko blir dräktig. Om kon inte blir dräktig inom en viss tid slås kon ut på grund av infertilitet. Dräktighetsutfallet i modellen följer en uniform fördelningsfunktion. Beroende på effektiviteten i reproduktionen beräknas kalvningsintervallet för varje ko. Kalvningsintervallen summeras för att beräkna besättningens genomsnittliga kalvningsintervall. Kalvningsintervallet ligger sedan till grund för beräkning av mjölkavkastning, mjölkintäkt och foderkostnad.

Genom besök på gårdar och internationell statistik har två fallgårdar skapats. Den ena gården är belägen i norra Italien. Gården karaktäriseras av en hög av grad av specialisering, utan betesdrift med högt avkastande kor. Besättningen består av 400 kor. Gården är typisk för större västeuropeiska och nordamerikanska mjölkgårdar. Den andra gården är belägen i sydvästra England. Gården drivs mer extensivt med en mindre besättning, 150 kor. Korna har något lägre avkastning och betar i viss utsträckning.

Modellen simulerar det ekonomiska resultatet i en situation med eller utan aktivitetsmätare. Skillnaden i resultat utgör vinsten hänförlig till aktivitetsmätaren. En introduktion av aktivitetsmätare visar att gårdarnas resultat förändras med 70 € till 251 € för den italienska gården och från 8 € till 178 € för den brittiska gården. Betydelsen av den nya tekniken varierar men är som störst för den italienska gården. Resultatet påverkas starkt av gårdens reproduktionsstatus när systemet introduceras. Det ekonomiska resultatet för en gård med sämre initial reproduktiv effektivitet påverkas därmed relativt sett mer jämfört med en gård med en initialt högre gard av effektivitet.

Mjölkavkastning, foderkostnad och rekrytering visar sig ha en betydande inverkan på resultatet. En förändring av dessa parametrar ger de största förändringarna i det ekonomiska resultatet. Ursprunglig reproduktiv effektivitet i besättningen samt de förbättringar som orsakas av aktivitetsmätaren är därför avgörande för resultatet.

Key terms: Fertilitet, Mjölkko, Aktivitetsmätning, Kalvningsintervall

Table of Contents

1 Introduction

One of the primary goals of the last century's dairy cow breeding has been to increase the milk yield. This goal has been well achieved and to day dairy cows are high performing animals, producing large quantities of milk. However, the goal of high milk yield has turned focus away from other qualities such as health and fertility. High milk yield and reproductive traits correlates and is associated with phenotypically and genetically reduced reproductive performance (Nebel & McGilliard, 1993).

The problem with poor fertility is considered to be the most important problem within the dairy industry. Decreasing fertility with 1-0.75% in conception rate annually over the last three decades has contributed towards a conception rate of less then 40% for US dairy cows. A study by Esslemont and Kossaibati (2002) estimate that the cost of sub fertility accounts for two thirds of the costs related to poor health and fertility. By increasing fertility by 10% the UK dairy industry would gain economic benefits of approximately £300 million (Garnsworthy 2005).

Low fertility causes a number of costly problems for dairy herds' world wide. As maximized net farm income is associated with an average herd life of five years, which equals a replacement rate of 20%, dairy farms are managed far from the economic optimum due to poor fertility of the cows (Jagannatha et al 1998). Low fertility also affects culling. Many dairy farms barely keep up with replacing cows. Due to low fertility and disease, culling for low yield is not possible. This is a problem that affects the possibility to increase milk production in the dairy herd (Gustafsson, 1997).

Management of dairy cows strives for a calving interval of 12 – 13 moths. A calving interval of this length maximizes milk yield as well as net farm income (Hollman, 1984). A lactation period of 12 moths implies that insemination has to be completed around the time of peak milk yield. By this time the energy balance of the cow is negative and signs of heat are difficult to detect. As the heat is hard to detect, conception at the optimal point of time is difficult to obtain and the number of open days tends to increase.

1.1 Problem

One of the reasons to why fertility numbers are low is that the cows of today show poor signs of heat, which causes a wide number of problems. The number of open days increases as well as the number of dry days. The total result is lower milk production per cow per year and less income for the dairy farmer. As fertility becomes a problem so does the recruitment. Cows are culled too early because of low fertility and the number of calves borne decreases. With an average of less than two lactations per cow the recruitment rate become negative. All of these issues mentioned result in problems for the managers to maintain the size of the heard without buying heifers. Milk yield and net farm income decrease and more time have to be spent on heat detection.

On the market for dairy management tools a variety of heat detection devices are sold. They vary from simple stickers attached to the cow, to highly advanced heard management systems. Pads, attached to the cow, change color as the cow is in heat is one example of simpler solutions. One of the more advanced solutions on the market for heat detection tools is activity meter systems. The general function of these systems is an activity meter attached to the cow. The meter sends information about cow activity to a central computer. The computer interprets the information from the activity meter and makes it useful for heat detection of individual cows.

DeLaval markets an activity meter system which is a part of the ALPRO® dairy heard management system. The DeLaval activity meter system has proved to be a reliable tool for heat detection. It detects heat with a hit rate as high as 94% and thereby helps to improve fertility (De Mol. 2000). As the biological benefits of the system are well documented, proving a system beneficial compared to conventional heat detection, its economic effects on dairy enterprise are not analyzed. For the individual entrepreneur the economic impact of using the system is just as important as the biological improvement. Every investment has to yield returns in terms of improved efficiency in order to utilize the resources of the farm.

1.2 Aim

Assuming that improved heat detection causes a more efficient use of the dairy farm resources, the activity meter is presumed to have a positive effect on the economy of the dairy farm. The aim of this study is to develop a model to analyze the profitability of the activity meter system at farm level. The model takes into account resources saved when using the activity meter system and evaluates the economic benefits for the dairy enterprise.

The model developed is intended to be used in the field by the DeLaval staff when promoting the activity meter system world wide. To enable the model to be useable in the field the parameters of the model have to satisfy a few specific demands. The parameters have to be found easily either at the farm or in national dairy statistics. Some general assumptions may have to be made.

Hence, this thesis intends to answer to the question following:

- How is the cost of recruitment affected by using the De Laval activity meter system at farm level?
- How the activity meter system does affect the total economic result of the dairy enterprise?

2 Background

2.1 Dairy herd management

Dairy herd management is a complex activity with high demands on the staff and management skills. Activities such as feed management, breeding, business management, milk quality monitoring and handling staff of different skills are all part of dairy herd management. (van Horn,1992)

Modern dairy farming is characterized as a capital intensive business with small economic margins (van Asseldonk, 1999). This means that a minor disturbance to production can lead to major economic losses. In this type of environment managerial practices are of critical importance. As the development continues towards larger herds and more precise management the need for improved information systems is growing (van Asseldonk, 1999).

One of the more important objectives of dairy herd management is reproductive management. Reproductive management has two primary objectives:

1. Establish or re-establish lactation and maximize feed conversion efficiency
2. Produce genetically superior heifer calves as herd replacement

The first objective is related to the lactation curve, as the lactation-curve peaks in the early stage of the lactation and gradually diminishes in the progress of the lactation. Pregnancy has beneficial effects on mammary gland function and feed conversion efficiency. The second objective, which is applicable to most dairy herds, is usually a cost effective measure to increase average herd milk yield. If the heifers are of higher genetic quality the herd will increase the milk yield and the recruitment heifers can also be used to increase the herd. (Macmillian, 1992)

2.1.1 Fertility of the dairy cow

During the last centuries dairy breeding has been strongly focused towards increased milk yield. However, high milk yield has been shown to correlate genetically with poor fertility. The combined result of these two factors is a growing problem with low fertility. In fact, sub fertility has grown to become one of the most important and costly problems for the dairy industry.

The most important economic factors in dairy herd management are the calving interval (CI), culling and the age of heifers entering their first lactation. (Gustafsson, 1997)

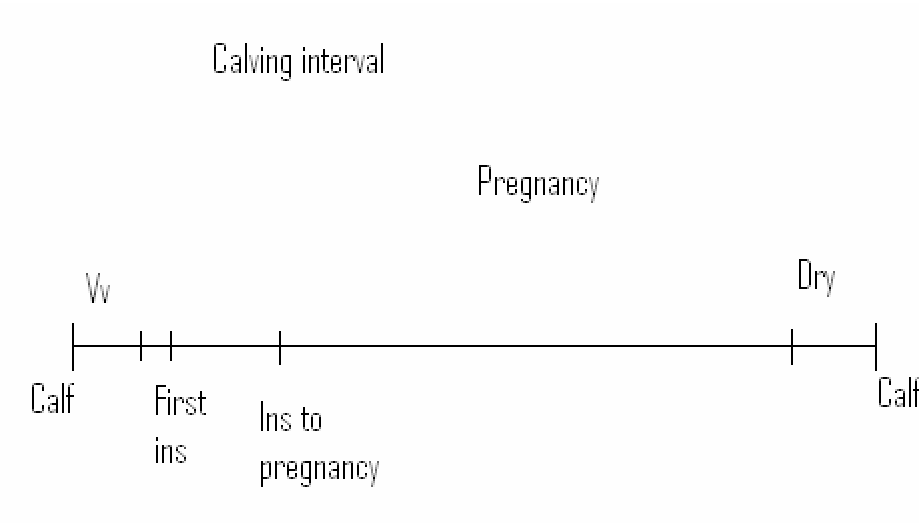


Figure 1: The parts of the calving interval

The fist phase is the voluntary waiting period (Vw). This is the time span from the calving to the first intended insemination of the cow. This period is a part of the management strategy of the desired length of the CI. In practice there is a time span from the intended, first insemination to the actual first insemination depending on when first heat occurs and if this heat is detected. If the cow doesn't become pregnant with the fist insemination the next heat has to be detected and insemination be conducted. This process is repeated until the cow becomes pregnant, or culled due to infertility. The ability to spot and detect cows in heat is measured as heat detection rate (HDR). The product of HDR and the number of services per conception (CR) determine the fertility status of the herd. The pregnancy and the voluntary waiting period can be considered fixed only the open period can be effected by management. Efficient breeding practices therefore strive to make the period from Vw to insemination causing pregnancy as short as possible.

Heat can be divided into three different phases: pre heat, heat and post heat. Cows show different signs during the different phases. During post heat and heat the vulva is swollen and mucus can be seen. As the cow moves from pre heat to heat her activity increases and peaks in early heat. Other cows are seen mounting the cow in heat. During post heat the activity decreases and bleeding appear. (De Laval)

2.1.2 Milk yield and the length of the lactation

The length of the lactation, or calving interval, is a commonly used measure in dairy herd management. The calving interval is the time from when one calf is born until the next calf is born. This time is affected by the interval between when the calves are born and the inseminations leading to pregnancy. To enable high milk yield and profitable milk production the length of the lactation period is of great importance. A calving interval (CI) of 12 months is commonly perceived to be the economically optimal CI. The highest yielding herds in the Swedish dairy statistics have a calving interval of 12 months (Gustafsson. 1997).

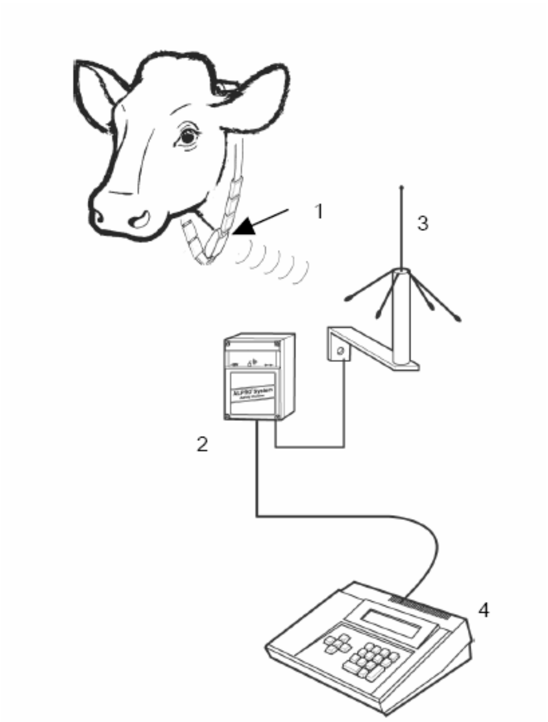
2.1.3 Culling and replacement

As mentioned above the second major impact on the dairy herd economy comes from the replacement rate. Replacement affects the economic result in a couple of ways. Replacement may be done voluntarily or involuntarily. Voluntary culling often occurs early in the cow's life due to low milk yield. Involuntary culling is associated with low fertility or other health problems. 20% of the total culling is caused by infertility. As the lifetime profitability of a cow increases with a growing number of lactations involuntary culling contributes to lower the profitability. (van Horn, 1992)

2.1.4 De Laval activity meter system and heat detection

Among the available decision support systems for dairy herd management the De Laval activity meter system is one. The system is a part of the ALPRO® dairy herd management system. The Alpro system is an integrated computerized system for milk yield monitoring, feeding and activity metering. Alpro contains a cow calendar which helps in breeding management.

Cow motion patterns do not differ much from day to day. In a free stall system cows are eating, ruminating, resting and being milked on regular basis. The fact that cows are regular in their motions creates a pattern that is easy to observe. The regular activity pattern of the cow is the basis for the heat detection process.



The activity meter system is based on 4 basic components:

1. Activity tag attached to the cow bracelet
2. Receiver
3. Antenna
4. Alpro processor

The activity tag is recording activity every 14,11 seconds. During a recording period activity is measured as either 1 or 0. The activities are summed as activities per hour. Data from the tag is transmitted to the receiver every hour and contains data from the last 24 hours. Data is then stored in the processor for 48 hours. The processor processes the activity data and produces an activity list of individual cows.

Figure 2: The components of the DeLaval activity meter system.

The activity meter system measures activity as described and creates a motion pattern for every cow carrying an activity tag. The motion pattern is shown hour by hour and is visualizing resting periods and periods of activity. The activity pattern is continuously updated through calculations by a Kalman filter. A Kalman filter is a mathematical formula comparing and predicting hour by hour data to create an activity pattern for each cow. The formula can be described as follows:

$$X(n) = F(n) * [\text{Today's values}] - F(n-1)*[\text{Yesterday's Values}] + G(n)*X(n-1)$$

The latest sending of data will always have the greatest impact on the calculation while old date lose importance as days pass. This enables the process to follow changes in the cow behavioral pattern.

As the day progress activity varies as the cow is carrying out her daily routines. The actual activity level is therefore not what detects heat. Data from the activity meters is evaluated hour by hour continuously and compared with data from the previous six hours. If data during this time diverges enough from the usual pattern the processor reports unusual high activity for that particular cow. As the system also reports the starting time of the activity the optimum time for insemination can be determined. Unusual high activity can be displayed within three degrees of certainty shown with one, two or three plusses.

2.2 Economy of reproduction

Herd profitability is strongly affected by the reproductive performance. Rougoor (1999) studied the relationship between fertility management and gross margin on 38 dairy farms in the Netherlands. Aspects related to fertility management such as CI, culling rate, number of days open are all strongly correlated to herd gross margin.

A measure of the reproductive effectiveness is pregnancy rate. It measures the number of cows that got pregnant during a period of time of the total number of cows that were eligible to get pregnant. Pregnancy rate can also be explained as the speed at which cows become pregnant following the voluntary waiting period. Pregnancy rate is calculated as conception rate time's estrus detection rate. By improving the pregnancy rate, open days are decreased.

To illustrate the pregnancy rate a heat detection rate of 50% is assumed. The average insemination is 1,8 inseminations per pregnancy, the conception rate is then 1/1,8 = 56%. In this case the pregnancy rate is 50% * 56% = 28%. When pregnancy rate is known, the number of days open is easily calculated as (1 / pregnancy rate) * 21 days. 21 days is the length of the estrus cycle. In this case we have (1 / 0,28) * 21 = 75 days open after the voluntary waiting period. (Own calculations)

Different studies use different approaches to determine the economy of reproductive management. In order to obtain a realistic economic assessment of improved reproductive performance all aspects affecting the cash flows must be accounted for. Costs and revenues from milk production must be accounted for as well as the lactation curves, feeding, culling etc. De Vries (2006) also take into account risks of involuntary culling, effects from voluntary culling and the performance of replacement heifers and the risks associated with fresh cow problems.

Economic evaluation of improved reproductive performance can be measured in a number of ways. The cost of an extra day open at a specific point of time in the lactation is one measure of the value of improved reproductive performance. In these cases the costs of an extra day open increases as the lactation progress. Reproductive improvement may also be evaluated as the value of one percentage unit of increased pregnancy rate, estrus detection rate or conception rate. Figures from different studies by de Vries (2006) show costs from an extra day open ranging from \$0,42 to \$4,95 (2003 US \$) depending on the point of time of the lactation. The cost of one percentage unit improved pregnancy rate was calculated to \$0,86 per cow per year when the pregnancy rate was approximately 0,45 and \$16,6 (1994 US \$) at a pregnancy rate as low as 13% (Plaizier, 1998)

De Vries (2006) uses a number of ways to display the economic gains from improved fertility. Assuming that a cow has approximately one first estrus cycle per year the net return of the improved fertility is interpreted as the maximum extra expenditures that could be allocated to improve conception rate in first estrus. As persistency of lactation decreases, the net return from improved conception rate in early lactation increases.

Retained pay off (RPO) is one additional approach to show the economic value of improved fertility. RPO is the value of all future cash flows from two identical cows, one open and the other pregnant. RPO is also denoted as the future profitability of a cow or cow value and is the difference in the future expected net returns of keeping her until the optimum time of voluntary culling or immediate culling and replacing her with a pregnant heifer. RPO depends on the lactation number, milk yield, days in milk, risk of involuntary culling and pregnancy status. The difference in RPO between the two cows shows the value that can be spent on efforts in order to get a cow pregnant in a certain stage of the lactation. (de Vries, 2006)

2.2.1 Automated estrus detection

Estrus detection is very important to dairy farming. Estrus detection determines the calving interval and is therefore an important factor that affects farm profitability. Estrus detection is usually done manually observing cow behavior. A cow in heat behaves differently and diverges from her normal behavior. This behavior can be seen as cows standing to be mounted, licking and being more active. Visual observation of heat has become more difficult over the last decades as cows show weaker signs of heat and herds are growing. (De Mol, 2000)

The automated estrus detection systems improve fertility in two ways. By making heat detection more effective a larger number of cows are detected and thereby inseminated. A larger number of detected cows out of the eligible cows during a time period increase the heat detection rate. This is one of the two factors that determine the pregnancy rate. The other factor is the conception rate, the number of inseminations per conception. If the activity meter system is able to determine the starting time of the increased activity, an optimal time of insemination can be determined. The time of insemination is a crucial factor to facilitate pregnancy.

2.3 SimHerd

Milk production, being a complicated interaction between the dairy farmer and the production system is unique for the individual herd. When production is changed analysis of the herd and prognosis of the effects may be of great use to predict the output of the production. To obtain a proper prognosis it has to be based on conditions of the actual herd. (Østergaard, 2004)

SimHerd is a dynamic, mechanistic, and stochastic model predicting herd performance over time. The model uses each cow and heifer individually. The cows and heifers are described by states such as milk yield, weight, reproductive- and health status etc. The prediction is made on a one week basis for each animal. Input consumption and production for the individual animal and the herd is calculated. Based on random numbers using relevant probability distributions the model generates discrete events like pregnancy, diseases and culling. The performance of the herd is determined indirectly by simulation of production and change in state of the individual animals. (Østergaard, 2004)

Technical annual results are presented over a period of maximum 10 years. Repeated simulations with the same initial settings of the herd may generate varying results. The varying results are due to the stochastic elements of the model. (Østergaard, 2004)

3 Method

The basis of the analysis is a mathematical simulation model. The model can be described as a modified waiting line simulation (Anderson. 2000). The cows become pregnant based on heat detection rate and conception rate and are culled based on a cull rate or infertility. These parameters determine for how long a cow stays in the system and how many lactations she performs during a lifetime. The simulation is generated in Visual basic (Windows).

Input data for the model is obtained from case farms, international dairy statistics and from experts in the dairy industry in different countries. The information gathered is the basis for a case farm where the economic consequences are analyzed before and after the introduction of the activity meter system. The objective function of the model is:

$$\pi = \left(\sum_{n=0}^{T} V_{nAM} \left(1 + \frac{i}{M}\right)^{-n} - \sum_{n=0}^{T} V_n \left(1 + \frac{i}{M}\right)^{-n} - C_{AM} \right) \times 0{,}0954 \qquad 3.1$$

Where π is the annual net revenue with activity metering and V_n is the annual net revenue without activity metering. C_{AM} is the cost of the activity meter system. The annual net revenue is discounted to T = 0 using $(1+ {}^{i}/_{M})^{-n}$ where i is the annual interest rate, M is the number of conversion periods per year and n is the year. The annuity factor is 0,0954

Due to the complexity of the problem some limitations have been made. The revenue calculations are done comparing milk yield and feed cost, cost of replacement, breeding and calves. The net revenue of the activity meter system is the difference in net revenue with activity metering compared to traditional management of the herd.

4 Description of the model

4.1 General description

In this part the model is described. General assumptions, restrictions and connections are presented. In the main presumptions are presented as well as some of the basic mathematical relations. Parameters referred to in chapter 4.1 are more closely described in chapter 4.2

4.1.1 Waiting line theory

In order to help managers understand and make better decisions concerning waiting lines, models can be developed. In the management science the theory dealing with waiting line theory is known as queuing theory. The operating characteristics of a waiting line are determined by mathematical formulas and relationships. (Anderson. 2000)

One simple kind of waiting line can be illustrated by a hamburger restaurant serving food to their customers. The hamburger restaurant has one service station through which each customer must pass to place an order. This is a single channel – waiting line. The arrival of customers is random. The waiting time of each customer entering the restaurant is dependent of how many people are already in the line, how long time it takes to serve each order. (Andersson. 2000)

4.1.2 The dairy herd waiting line simulation

Due to the nature of the problem, the problem of a waiting line of cows has to be slightly modified to fit a dairy herd. A cow is assumed to arrive to the waiting line after having calved and passed through the voluntary waiting period. Arriving at the waiting line the numbers of service stations are assumed to be infinite. Herd management is thereby assumed to be able to service any cow that is due to be served. The time a cow stays in line depends on the efficiency of the serving staff and the activity metering system. Efficiency is measured as conception rate (CR) and heat detection rate (HDR). (de Vries, 2006) Average time spent in the line can be expressed as:

$$W = HDR \times PR \times T_e \qquad 4.1$$

Where W is the time in line and T_e is the length of one oestrus cycle, 21 days. There is only one chance for management to serve the cow during an oestrus cycle. HDR and CR is fixed in the initial settings, depending on a random number generated by a discrete uniform distribution in the simulation and matched to the two measures. A cow is either pregnant or not pregnant. The probability to detect a heat is expressed as:

$$P_s = HDR \qquad 4.2$$

And the probability of a successful insemination given that the heat is detected is:

$$P_{ins} = PR \qquad 4.3$$

The product of 4.2 and 4.3 is the probability that a cow is successfully inseminated, or served, and can leave the waiting line. This product is also referred to as pregnancy rate (PR), or the speed at which cows is getting pregnant. (de Vries, 2006) P_{ins} and P_s are fixed. A random number with a continuous uniform distribution generated by the model determines if the cow is pregnant or not. If the random number is smaller or equal to the possibilities a cow heat is detected and may be tested for insemination.

As the number of units in the system, herd size, is fixed the number of cows arriving to the waiting line is determined by two factors; the speed at which cows are rotating within the model and the culling rate. Circulation of cows within the model is determined by PR.

4.1.3 Distribution of random numbers

Random numbers used in the model follows a continuous uniform distribution or rectangular distribution. The distribution is described by using Y as a random variable.

$$F(y) = 1 / (b-a), \quad a \leq y \leq b \qquad 4.4$$

The equation describes a straight line and the area under the horizontal axis is rectangular in shape. The graph is rectangular with width (*a*-*b*) and height 1 / (*a*-*b*). The model uses *a* = 0 and *b* = 1, such a case is called the standard uniform distribution. (Rudolf et al. 1996)

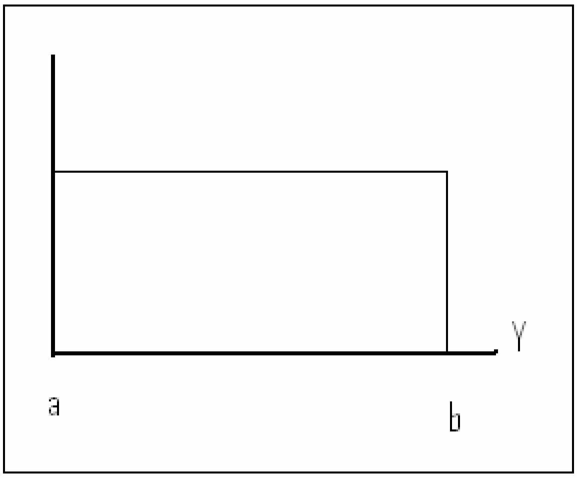


Figure 3. The probability function for the random variable Y (Rudolf J et al. 1996)

4.1.4 Description of parameters and their initial values

The model simulates the performance of the diary herd over a set period of time. The variables changed for every simulation are heat detection rate and conception rate. These variables are affecting the herd performance and thereby all relevant parameters. A change in pregnancy rate and conception rate affects calving interval, replacement and the age spread of the cows in the dairy herd. A change in these parameters affects:

- Milk yield
- Feed consumption
- Replacement
- Breeding
- Calves born

The economic consequences of activity metering will depend on the change in these measures.

In order to create a "herd" of cows to initialize the model, a number of data are entered into the user interface. The number of cows, dry and milking, is entered. Voluntary waiting period, length of the dry period and the number of days open are also entered. Culling that doesn't depend on infertility is entered as culling rate. Culling rate is a stochastic variable with a uniform distribution. These inputs are obtained from the case farm and enables the model to create a "herd" that is as similar to the real herd as possible.

All cows are numbered and the model keeps track of the lactation that a cow is currently in and the number of days she has spent in the current lactation. The cow may be in six different stages of the lactation:

- Voluntary waiting
- Open
- Pregnant
- Dry
- Culled on basis of -
  - Infertility
  - Other reasons – dependent of cull rate

The index letters *i*, *l* and *s* are the identification letters of the cows. A cow is identified as *i* being cow number, *l* the lactation the cow is currently in and *s* being the status referred to above.
Cow status is changed on a 21-day basis, the length of an oestrous cycle, depending on their current status and days in lactation. The voluntary waiting period is fixed as well as the pregnancy period and the dry period. The period during which a cow is open depends on how long it takes for a cow to get pregnant, or eventually culled due to infertility. Insemination is done once every 21-day if heat is detected during the period. The cow gets randomly pregnant depending on the heat detection rate and conception rate. Culled cows are kept in the model until the end of their current lactation.

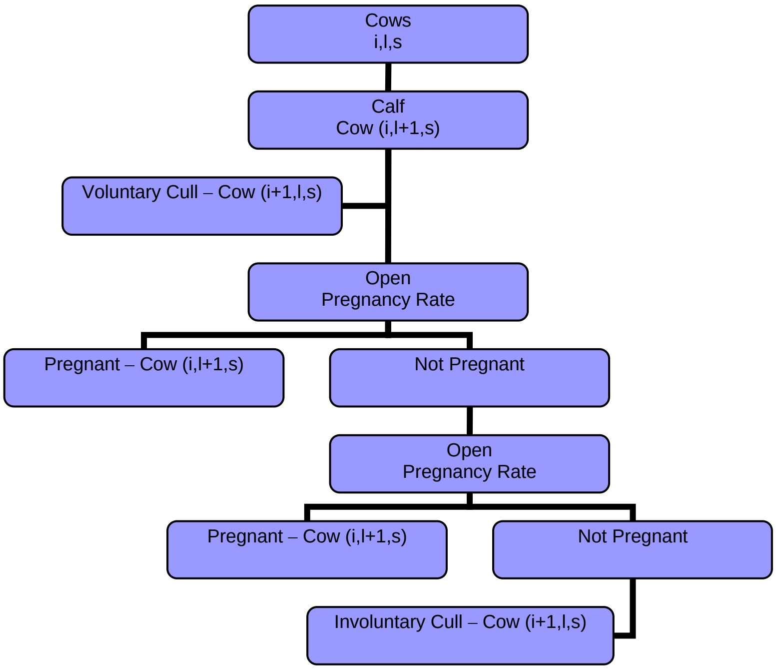


Figure 4: The cow way through the waiting line

Culling that is not caused by infertility is determined by the culling rate in the simulation. The cull rate describes the risk that a cow is culled due to low milk yield, normally referred to as voluntary culling. The cull rate also includes culling due to diseases and other dysfunctions, except infertility. This cull rate is obtained from the herd records of the actual farm. Cull rate is fixed and assumed not to be affected by the introduction of activity metering. Cows are tested for culling by a uniform distributed random number between one and zero following a uniform distribution. A number under or equal to cull rate generates a cull. Cows that are culled are always assumed to be replaced with a new heifer. The heifer is also assumed to calve on the day she enter the herd and is thereby bringing a calf.

Initial settings of the model herd origins from case farm herd records. The herd records are used to provide a herd with a structure of age and days in lactation similar to that in reality. Cow status, age and days in milk are determined on case farm basis and create the origin settings for following simulation.

4.2 Description of parameters

4.2.1 Heat detection rate, Pregnancy rate and Conception rate

Heat detection rate (HDR) and conception rate (CR) are the main parameters of the models. HDR times CR generates the pregnancy rate (PR). The effect of the activity metering on the herd is analyzed by changing HDR and CR. As described earlier changing heat detection rate and conception rate generates a number of effects. These effects are estimated through the simulations performed by the model.

The output of the model is compared to the output with and without activity meters. To obtain a more extended analysis of the activity meter system the initial settings are changed. The accuracy of the activity meter is referred to in a couple of studies. Murray (2005) performed a study in a grass land herd. He noticed an increase in CR and HDR from 27% to 52 % and 54% to 88% respectively. De Mol (2003) evaluated automated estrus detection in Dutch dairy herds, free stall farming. In this study heat detection was ranging from 63% to 94% using automated estrus detection.

4.2.2 Milk yield calculations

Milk yield calculations in the model are based on Woods gama-funktion, $Y_t = at^b * e^{-ct}$. Y_t is the milk yield on day t, e is the natural logarithm and a, b and c are constants adjusting the shape and height of the curve. The parameters b and c are altered from Strandberg (1989) and are different for cows in lactation one, two and three. All cows with more than three lactations are assumed to have a lactation curve identical to lactation three. The constant a is adjusted to give the curve a volume of milk that is appropriate for the production system and the lactation of the cow. The shape of the curve is assumed not to vary depending on production system.

The shape of the lactation curve tends to differ slightly for a pregnant cow and a non pregnant cow. The non pregnant cow has a more flat curve in the end of the lactation compared to a pregnant cow. The measurable effect of pregnancy is assumed to start on day 140 for a cow with 60 days open. As the number of open days increases the measurable effect shortens with 0,35 days per extra day open. (Strandberg, 1989) Pregnancy is impacting daily milk yield as a decrease in production with 0,1 litre per day. (Ekman. 1995) The decrease in milk produced is subtracted from the average daily milk yield for the cow in question.

As culled cows are culled due to different causes and their time period into the lactation differs widely in reality, their average milk yield is assumed to be the same as other cows. Using the given conditions milk yield is calculated as average daily milk yield.

4.2.3 Feeding

Feed is calculated individually for the two countries. Based on the ingredients in the feed mix, provided by local dairy advisors, a total mix ration is calculated. As the average daily yield changes the feed mix is adjusted to fit the current yield. Excess feeding of 20 % is accounted for. The feed mix is calculated for five levels of milk yield in the free stall system alternative and six yield levels in the Great Britain alternative. Feed mix calculations have been performed by Rolf Spörndly at the Swedish University of agriculture, Department of Animal nutrition and management.

Pasture is not accounted for due to several reasons. Pasture consumption is difficult to estimate. This is confirmed by interviews with farmers. High yielding cows were not let out to pasture and other cows are assumed not to consume more grass than required in maintains. Pasture also complicates feed mix optimization.

4.2.4 Culling and replacement

Culling and replacement is a function of the cull rate, which represents culling for low milk yield and diseases, and the pregnancy rate. A low pregnancy rate generates more cows culled due to infertility. The cull rate is fixed and depends on the case farm herd historical performance. A cow is tested once every lactation for culling. The test is conducted during the first 21 day period after calving. If the test decides to cull a cow she is not inseminated but is milked through the lactation. Swensson (1998) uses 168 to 350 days lactation periods for cows due to be culled. Cull cows in this simulation model are given a lactation length of 300 days. Heifers are assumed to represent a higher risk of being culled than older cows. First lactating cow culling rate is therefore eight percentage units higher than for the older cows (Svensk husdjursstatistik. 2005)

Culling due to infertility occurs if a cow does not become pregnant during the set time for insemination. This time is about seven estrus cycles following the open period. (Esslemont. 2003)

When a cow is culled, due to any reason, she is replaced with a new, pregnant heifer. This transaction is associated with a cost for the replacement. The model doesn’t keep heifers “in its barn” since all calves that are borne are assumed to be sold seven weeks after calving. The heifers that replace culled cows are assumed to be bought back on the culling day of the replaced cow.

The price of a heifer is the average price for heifers just before calving sold by the farm during the period. The cull cow price is the average price per kg live weight for cull cows at farm gate. (IFCN Dairy Report, 2005)

4.2.5 Calves

Every cow that enters a new lactation is assumed to bring a calf. Heifers entering production are therefore assumed to arrive at the farm, give birth to a calf and start milking the same day as the “old” cow is culled. Not all calves survive and the number of calves born at the end of the year is multiplied by a mortality factor of 92,3% since 7,7% of the calves are assumed not to survive. (Esslemont. 2003) Calves are further more assumed to be held at the farm for seven weeks before being sold. During this time they are assumed to be fed whole milk and a feed concentrate. The consumption of hay during this period is negligible and therefore not taken into account. (Mjölkkor, 1997)

Tabel 4.1 The demanded energy for the young calf (Mjölkkor, 1997)

Calf Weight gain > 500 g /day

	0 – 4 weeks, MJ/day	*5 – 7 weeks, MJ/day*
Milk	12,4	12
Conc feed	0,9	4,5

The cost of concentrate feed is calculated based on a concentrate consisting of corn or wheat and soy meal. A mix of the ingredients is made to match the energy need for the calf. The price on the ingredients is taken from the case farm.

When calves are born the cow is exposed to a risk of various diseases associated with calving. Diseases that afflict the cow are often costly in terms of treatment and production losses. To illustrate the risk of disease in connection with calving, calves are charged a cost of disease. Esslemont (2003) lists a number of diseases that occur close to calving. An average cost of 219 € per treatment is accounted for based on Great Britain veterinary costs. Data regarding the probability of disease is obtained from the Swedish Dairy Association statistics:

Table 4.2 The expected risk of disease due to calving expressed as percentage probability of disease (Lindberg, 2006)

Health problem	**risk**
*Clinical mastitis	0,1425
Puerperal paresis	0,0320
Retained placenta	0,0180
Calving problems	0,0080
Peripartum	0,0040
Total	0,2045

* 19% risk of which
75% are assumed
to be calving related

The expected cost of disease is then calculated as 0,2 x £ 219 = 44 € in the Mix alternative. By comparing the expected cost disease to the price of a Great Britain calf a recalculation factor is calculated for. Using the recalculation factor the price of the Free Stall case is calculated as being 38 €. (Own calculations)

4.2.6 Reproductive costs

The costs of reproduction refer to the cost of semen, labor required to inseminate and veterinary expenses. Time spent on heat detection is not assumed to be saved. The costs of semen is 22 € per dose for the Great Britain farm and 9 € per dose in the Free stall farm (Svensk Avel). Insemination is assumed to take 20 minutes per cow times a cost of labor of 13,3 €/h and 9,3 €/h for Great Britain and Italian farms respectively.

Pregnancy checks are assumed to take place once during every pregnancy period. The cost of a pregnancy check in Sweden amounts to around 5,4 € (Per Arnesson, personal message). This cost is divided by the farm wage to get an adjustment factor. Using the adjustment factor the cost of a pregnancy check is thereafter calculated to 3,87 €/cow in the Great Britain alternative and 2,70 €/cow in the Free stall alternative.

4.2.7 Cost of the activity meter system

The activity metering system consists of two antennas, one activity tag per cow and one ALPRO processor with ALPRO - Windows. The economic lifetime of the system is assumed to be ten years. A simulation over 20 years requires a reinvestment after ten years. Prices are shown in table 4.3.

Table 4.3 Price for the activity meter system
Two antennas per farm and one tag per cow being used

Activity meter system	
Activity tag	80 € / cow
Alpro + Win	4 207 €
Antenna	980 € / antenna
Instalation	1 000 €

4.2.8 Prices

Prices are mainly calculated from case farms and the IFCN Report (2005). Prices that origin from other sources are referred to as they occur. Prices from 2005 are recalculated for using the inflation rate of the countries respectively (Eurostat). All prices are presented in EURO. Exchange rates used in the study:

1 GBP = 1, 48 €
1 USD = 0, 76 €

(www.finansportalen.se)

4.2.9 Revenue calculations

Revenue calculations are conducted using the net present value (NPV) method. The NPV method discounts the sum of all future cash flows to a present value of t = 0, generating the net present value. Using a discounting formula to a nonuniform series of payments the cash flows for the two alternatives, with and without activity metering, are discounted to one specific point in time, t = 0. The difference between the net present values of the two alternatives is the value of the investment in an activity meter system. (Barry. 2000) The NPV function is displayed in equation 4.5:

$$NPV = \sum V_n \times (1+i)^{-n} \tag{4.5}$$

V_n is a net cash flow, i is the interest rate and n is the year the cash flow is generated.

Due to the nature of the simulation model, running on 21 day periods, revenue calculations can not be done on a one year basis. One “model year” is 357 days and all data is generated during this period, assuming that the “books are closed” on day 357. Therefore equation 4.1 can not be used without modification. Compounding has to be conducted for each 357 day period. In such case the “model year” corresponds to 357 / 356 = 1,0224 periods per year, referred to as M, being the conversion period.

The interest rate commonly is expressed as an annual interest rate. In this case however, the rate must be recalculated to reflect compounding on a 357 day basis. The new expression is expressed in equation 4.6:

$$V_{T=0} = V_n \left(1+\frac{i}{M}\right)^{-n} \tag{4.6}$$

As the economic lifespan of the system is ten years and simulation is conducted across a period of 20 “model years”, or periods, a reinvestment in the activity meter system has to be made after ten periods. The cost of the activity meter system is shown in 4.7:

$$C_{AM} = C_{T=0} + C_{T=0} \times \left(1+\frac{i}{M}\right)^{-10} \tag{4.7}$$

5 Case farms

5.1 Description of case farms

Two case farms are identified in order to examine the profitability of the activity meter system. The farms represent different types of markets with different conditions of dairy production. The farms are situated in Northern Italy and Southwest Great Britain representing intensive dairy production and a more extensive type of production. In the model the main differences of importance between the two farms are product prices, milk yield, feeding systems and herd size.

5.1.1 Great Britain – Free stall farm with cows grassing to some extent

The first farm, situated in Great Britain, is a combination of intensive free stall farming and extensive use of pasture. This production system is also referred to as the “mix farm” in the thesis. The Great Britain dairy farms are located in South West England and Southern Wales. Average size of a dairy farm in this area is about 100 cows. Management is conducted on a more individual basis and concentrate feed is fed through feeding stations.

Cows are maintained inside the free stall barn during the winter and are let out to graze from May to October. Pasture still is not a major part of the feed intake as cows are fed with a mixture of feed even during the grazing season. The main crops are grass for silage and pasture, corn for silage and whole crop silage. The ingredients in the feed mix are corn silage, grass silage, grass hay, caustic wheat, wheat/corn meal, soy, concentrate feed and minerals. Herd size is assumed to be 150 heads. The cows are of Holstein breed yielding about 9000 liters. Milk price amounts to 0,268 € / kg.

5.1.2 Italy – Intensive free stall farm

The first farm, referred to as the free stall farm, is situated in Italy. The Italian case farm is situated on the northern Po-plains close to Bergamo. This is a part of Italy with highly specialized intensive dairy farming. The cows are kept in large free stall systems and do not grass on pasture. Average herd size is around 200 cows. This farm represents the Western European and North American type of dairy farming with group management and fairly large herds. The loose house farm herd size in the study is assumed to be 400 cows.

The climate is warm and humid and enables crop farming with corn as a major crop. Corn is therefore the main ingredient in the feed mix. The cows are fed a mixed ration consisting of corn, grain and silage, grass hay, Alfa Alfa, soy bean and cotton seed.

The cows are of high yielding Holstein Friesian breed. Average milk yield per cow is about 10000 kg ECM per cow and year. The milk price is about 0,36 € per kg of milk.

6 Analysis

The results are obtained by running the model across four different scenarios using different assumptions regarding heat detection rate and conception rate. Average pregnancy rate in Holstein cows in Florida and Georgia was 17 % 1999 – 2000 with variations over the season. (de Vries. 2006). The simulation assumes 20 % as benchmark. Murray (2006) noticed an increase in pregnancy rate of 30 % due to introduction of activity metering. Based on the lower pregnancy rate and the increase noticed by Murray as an upper limit for increase four scenarios are defined. The four scenarios are simulated using the following assumptions with regard to the pregnancy rate:

Table 6.1 The four cases used for the analysis

1. 20 % without activity metering and 48 % with activity metering
2. 20 % without activity metering and 40 % with activity metering
3. 30 % without activity metering and 48 % with activity metering
4. 40 % without activity metering and 57 % with activity metering

The initial conditions regarding herd structure are varied slightly due to the nature of the case farms. The free stall farm is characterized by a slightly lowered voluntary cull rate, 15 % compared to 20 % for the Great Britain farm. The age distribution of the herd is also varied according to the case farm data. In the case of using the activity meter the cost of the activity meter system is affecting the results.

6.1 Great Britain - Free stall farm with pasture in some extent

The introduction of the new technology affects the performance of the farm in various ways. The calving interval decreases in all scenarios as well as the cull rate, and the average age of the herd increases. These effects cause a number of production data to change. The impact from the introduction of the activity meter upon production is more accentuated the lower the initial pregnancy rate. A wider spread between the initial assumptions regarding pregnancy rate with and without the activity meter also affects the result in a positive way.

6.1.1 Net Revenue

By examining the impact of the activity meter system in the four different scenarios an explanation of the result is easier to do and the change in different parameters is better understood. The net return of the investment in the activity meter system varies in the four cases, being largest in case one. The change of initial settings of the cases can be thought of as differently skilled management. As activity metering is introduced the herd increases its performance. Highly skilled management may not be as helped by the new technology as less skilled management. The effect of activity metering is displayed in table 6.2 which clearly illustrates that the result of activity metering is highly depended on the initial reproductive performance of the herd.

Table 6.2 The net present value of the investment in the four cases

Net present value of the investment (€)

Case	NPV
1	279988
2	270239
3	147493
4	12232

The net return on the investment may not be very informative, apart from supporting the previous statement. To better understand the impact of the new technology the net present value may be recalculated as revenue per cow per year. Using the annuity factor 0,0954 and dividing the product by the number of cows, a new measure of the revenue is created. Figure 5 displays the annual net revenue per cow in the four cases.

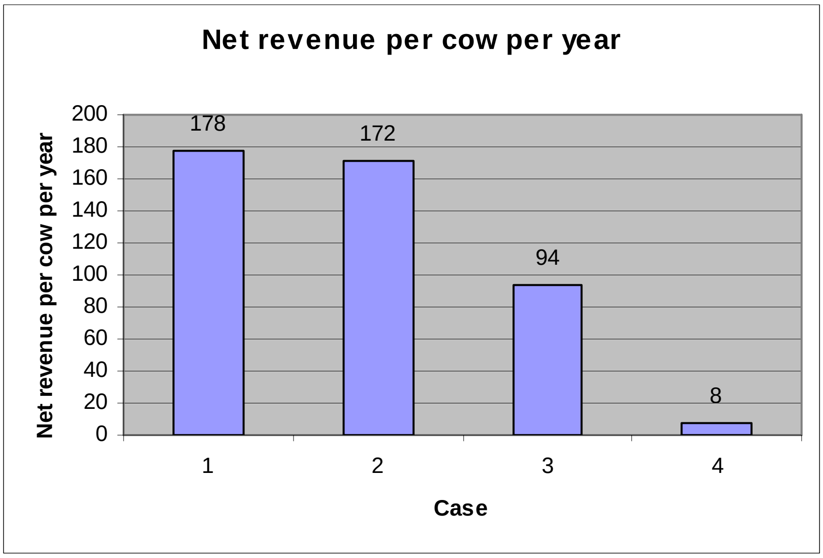


Figure 5. The net revenue per cow and year expressed as € per cow and year.

The results per cow per year vary widely between the scenarios. In scenarios one and two the gain is relatively large compared to scenario three and four. Reproductive performance without activity metering is assumed to be the same, 20 % pregnancy rate, in case one and two. The increase in the pregnancy rate is 28 percentage points and 20 percentage points in case one and two respectively. As the initial pregnancy rate increases the net revenue decreases. In case three with 30 % initial pregnancy rate increasing to 48 % the net revenue is about half of the revenue in case one and two. Still, the net revenue in case three is fairly high. Case four with a 40 % pregnancy rate as initial herd performance increasing to 57 % still generates a net revenue but it is low compared to the other three scenarios.

To facilitate the understanding in figure 5 the net revenue may be analyzed in terms of the parts contributing to the gain in the net revenue. Milk yield, feed costs, replacement, breeding and calf are the major components contributing to the results.

6.1.2 Milk revenue net of feed cost

Using the initial settings of the four cases gives five different settings for the pregnancy rate, 20 %, 30 %, 40 %, 48 % and 57 %. This yields some interesting results. Using the results from these simulations, not comparing the net revenue with and without activity metering, recalls interesting effects.

As described in previous chapters a change in the pregnancy rate has an impact on the calving interval. A changing pregnancy rate as in the scenarios supports this statement. As pregnancy rate increases the calving interval decrease.

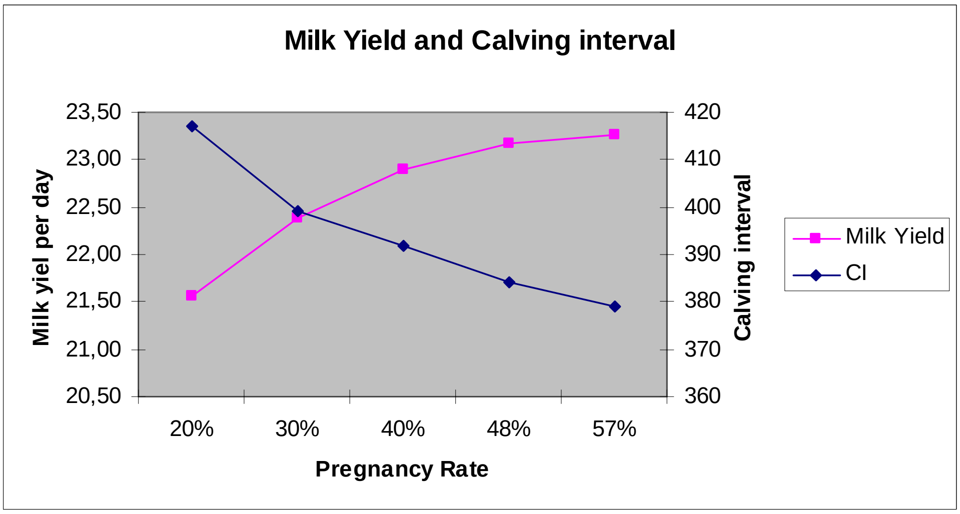


Figure 6. The effect of an increase in the pregnancy rate upon the average calving interval (days) and the average daily milk yield (kg / day).

As illustrated in figure 6 the pregnancy rate also affects the milk yield. Average daily milk yield increases as the pregnancy rate increases and calving interval decreases. The explanation comes from the functional form of the lactation curve. Since a maximum is obtained in the early stages of the lactation diminishing in the remainder of the period the cow is most productive in the first part of the lactation. Shortening the lactation period reduces the number of lactation days where the cow is less productive, enabling the cow to reach the more productive stages of the lactation more frequently.

Increasing milk production also affects the consumption of feed. More milk demands more feed and thereby cause an increase in the total feed cost. As cows spend more time in the early stages of the lactation, due to a decreased calving interval, feed conversion efficiency increases. The maintenance feed required by the cow during the lactation is more or less constant during the lactation period. As milk yield increases a smaller share of feed is needed as maintenance feed.

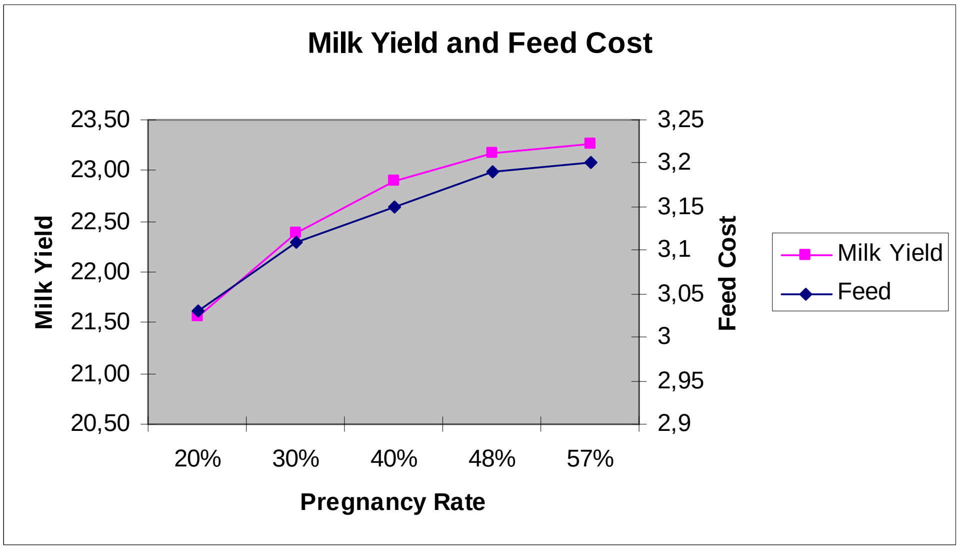


Figure 7. Pregnancy rate effect on milk yield (kg / day) and feed cost (€ / day).

Figure 7 illustrates the effect described in the previous text. Milk yield increases at a higher rate then the feed cost. An increase in milk yield is not associated with a proportional increase in feed cost. In the different scenarios, regarding reproductive performance, the relative effect of increasing milk yield and feed cost provides a noticeable effect upon milk revenue net of feed cost. The key measure milk revenue net of feed cost is therefore affected in a positive manner. The relation between pregnancy rate, milk yield and feed cost contributes substantially towards explaining the positive impact of the activity meter system.

Using the change in milk revenue net of feed cost per day the total net revenue per cow and year is calculated. The total impact on net revenue due to a change in milk revenue minus feed costs is 99 € in case one, 87 € in case two, 47 € in case three and 16 € in case four. Hence, the impact of milk revenue net of feed cost represents about half of the total economic gain of the activity meter system.

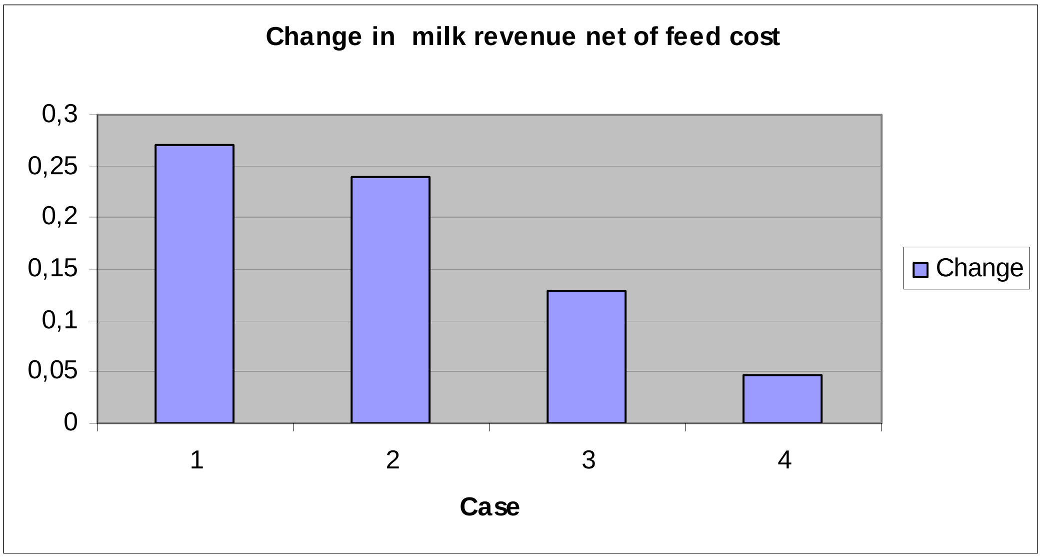


Figure 8. The change in daily milk revenue net of feed cost (€ / day).

6.1.3 Cost of Replacement

The cost of replacement may be calculated in various ways. The method used in this model is to subtract the cull cow value from the cost of acquiring a pregnant heifer. The production loss due to the exchange of an older, higher yielding cow for a heifer does not directly affect the replacement cost. This effect is taken into account in the milk yield calculations and affects the average daily milk yield.

The impact of replacement in the scenarios is found to be the second major affection on net revenue of the system. As cull cows are paid a low price when exiting the herd and heifers are far more expensive a price wedge is created that causes a cost of culling a cow. The wider the span the larger the effect on replacement cost.

Using the initial assumptions in the model the following results are generated. The difference in the cost of a heifer and the price paid for a cull cow is 780 €. This is the cost referred to as the price wedge. In scenario one and two, with a change in the cull rate of about 15 % the replacement cost decreases with about 117 €. In the case where the change is only 6,4 % cost decreases with 50 €. In the fourth case the simulations reveal a slight increase in culling causing an increased cost of replacement.

In the model culling is divided in two parts, culling caused by infertility and culling caused by other causes. Other causes may be various diseases and low milk yield. The expected cull rate due to these causes does not vary between the four cases.

The simulation reveals that the pregnancy rate affects culling due to infertility. By decreasing the pregnancy rate the average time period required for a cow to become pregnant increases. If a cow does not become pregnant within a fixed period of time she is culled. A decreasing pregnancy rate increases the probability that a cow is pregnant within the fixed period for insemination. If pregnancy rate is low, more cows are at risk of being culled due to the described effect.

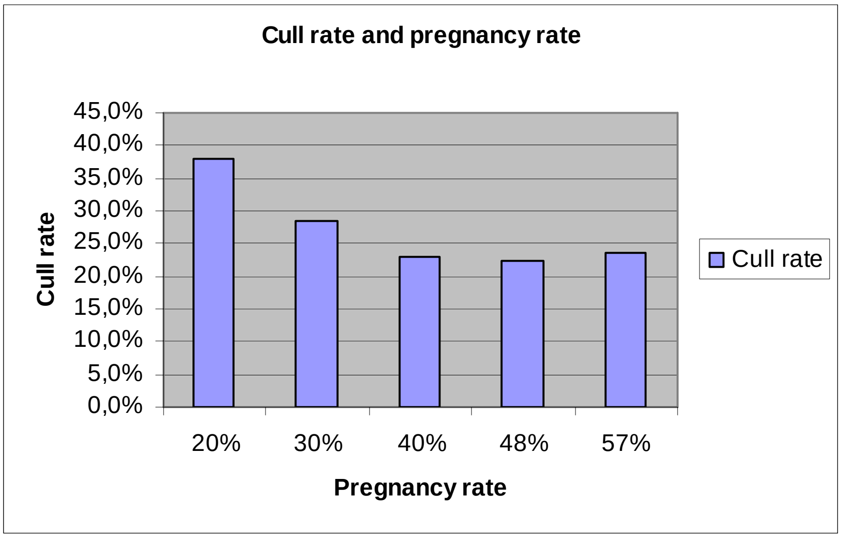


Figure 9. The relationship between pregnancy rate and total cull rate.

6.1.4 Breeding and calves

Breeding costs and the value of calves contributes only marginal as to the economic result of the system. As the calving interval increases more calves are born per year. The calf generates revenue when it is sold. This revenue is an average market price for a calf. The net value of the calf however is affected by two types of costs. The calf is fed on the farm for seven weeks, consuming milk and some concentrate feed. Giving birth to a calf is also associated with a risk that the cow is exposed to various diseases close to the time of calving. The fact that diseases are costly and that more are calves born per year increase the expected cost of calving. Calving being a risky moment all calves is associated with an expected cost of calving, dead or surviving. However only living calves generates an income to the farm. Due to a low price paid for a calf and the costs associated with the risk of disease, the net value of a calf is low. A comparison of the scenarios reveals a slight decrease in calf revenue as pregnancy rate increase.

The cost of breeding consists of semen costs, pregnancy checks and the time spent on each insemination. The number of inseminations per year and cow depends on the conception rate and the heat detection rate. If the heat detection rate is high, heat is typically observed. However, if the conception rate is low many inseminations are needed per pregnancy and the cost of breeding would rise.

As with calves no big difference is seen on the breeding cost with or without activity metering. The change is ranging from 1 € to 5 € in decreased costs. As fertility is improved the number of inseminations per pregnancy is lowered and should cause decreased costs. However, improved fertility and shortened calving intervals result in a slight increase in the number of pregnancies per cow per year, causing an increased cost of breeding

6.2 Italy – Intensive free stall farm

As on the Great Britain farm, the activity meter has a major impact on the economic result on the free stall farm. The simulation reveals a positive impact on net revenue, due to the shortened calving interval. The net revenue of the system has the same sources as on the mix farm but differ in magnitude and distribution. The differences in costs and prices create a multiplier effect that is different compared to the Great Britain farm.

6.2.1 Annual Net Revenue from introducing the activity meter

The net revenue generated by the activity meter varies in the four cases. Case one and two, with initial low reproductive performance, report the highest revenue. However, the increase due to introducing the activity meter system does not correspond proportionally to the increase in total revenues. A comparison of case one and two reveals a different impact on the net revenue than observed on the Great Britain farm. Case one and two are simulated with the initial settings of 20 % pregnancy rate. In case one pregnancy rate increasing by 28 %, reveals a slightly smaller profit compared to case two, increasing PR by 20 %. Case three and four show fairly high revenue despite the fact that the pregnancy rates are high compared to case one and two.

Case one and two displays an annual net revenue of 1050550 € and 1079981 € respectively. Case three and four are less profitable but still show a good result. The annual net revenue is 446971 € and 292988 € for case three and four respectively. The net revenue per cow and year is shown in figure 10.

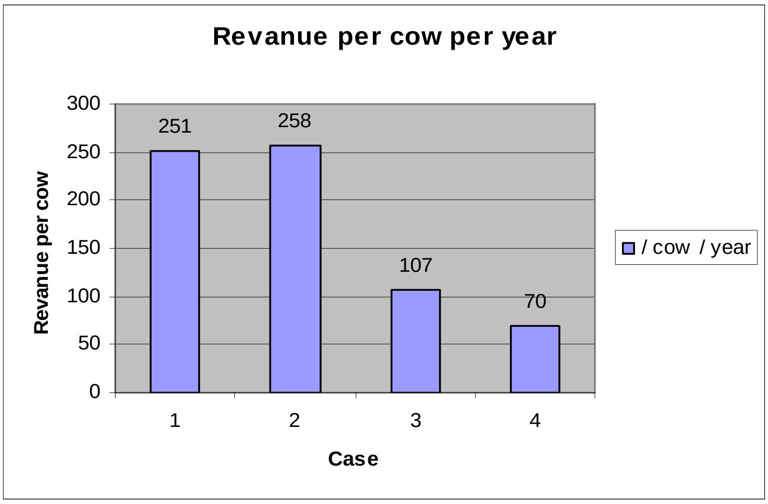


Figure 10. The net revenue per cow and year expressed as € per cow and year.

The annual net revenue per cow per year is ranging widely in the four cases. However the result is fairly large, even in case three and four. As in the mix farm cases the annual net revenue per cow per year are better explained by analyzing the different parts contributing to the net revenue.

6.2.2 Milk revenue net of feed cost

Pattern displayed on the Great Britain farm regarding pregnancy rate, calving interval and milk yield are similar to the free stall farm. The free stall farm benefits from a larger increase in milk yield as calving interval decreases. One explanation to the larger increase is found in the lactation curve. Due to the form of the free stall cow lactation curve, the increase is slightly larger compared to a cow with a lower milk yield. The whole lactation curve is shifted upwards as a larger volume is produced.

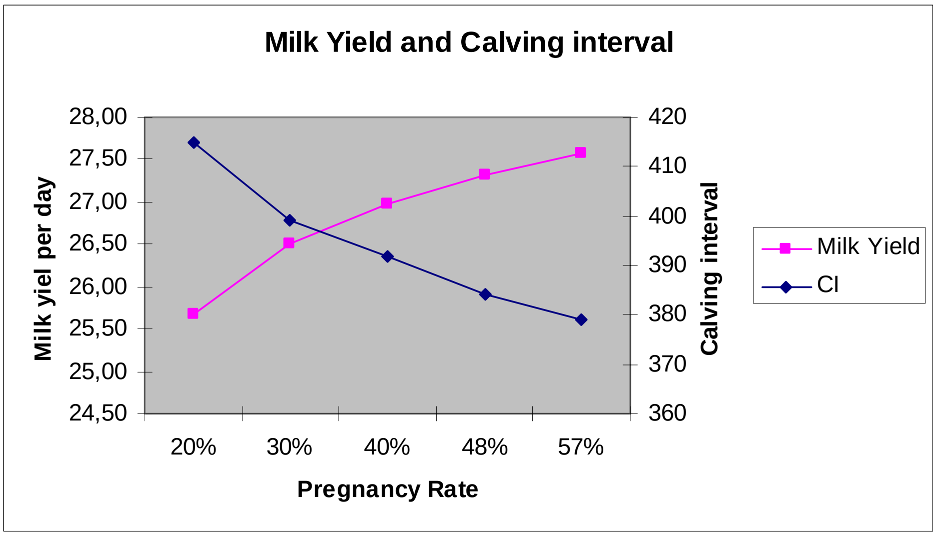


Figure 11. The effect of an increase in the pregnancy rate upon the average calving interval (days) and the average daily milk yield (kg / day).

Feed consumption follows a similar pattern as for the Mix farm. A slight difference is observed as the change in feed cost is not as smooth as the change in milk yield. The relation between milk revenue net of feed cost per day is still increasing as milk yield increases. By calculating the relation milk revenue per day divided by feed cost per day the milk feed cost ratio is calculated. The higher the ratio the better, less feed is used to produce one liter of milk. For the 20% pregnancy rate the ratio is 2,49 and it increases to 2,58 as pregnancy rate increases to 57%.This increase is the effect attributable to the positive effect on milk net of feed costs as pregnancy rate increases.

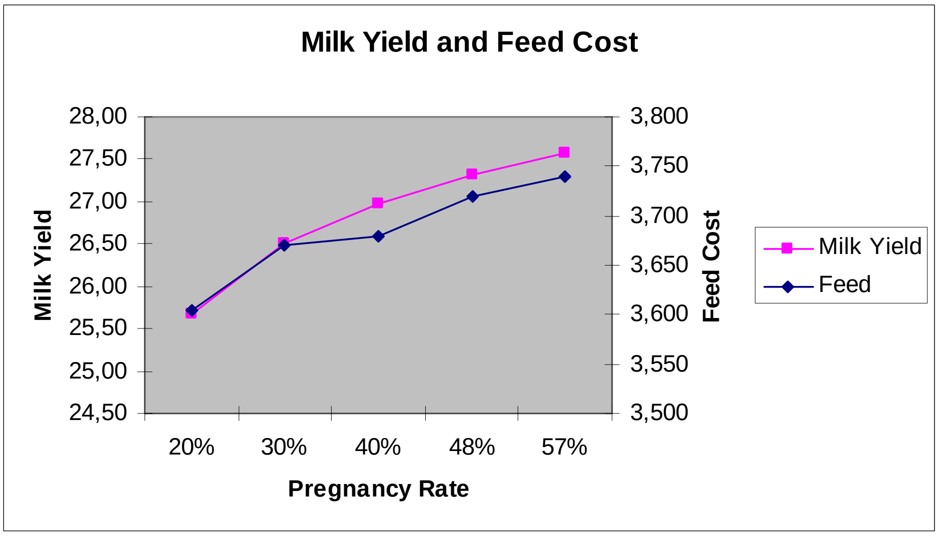


Figure 12. Pregnancy rate effect on milk yield (kg / day) and feed cost (€ / day).

Figure 12 explains the effect on milk revenues net of feed cost in the four different scenarios. In case one and two the change is about 0,45 € per cow per day. On a one year basis this decrease in feed cost per kg milk is generating a net revenue of 164 € per cow due to the activity meter system. Case two and three shows a smaller increase in milk revenues net of feed cost with a change of 0,062 € per cow per day, which corresponds to a gain of 22,6 € per cow per year.

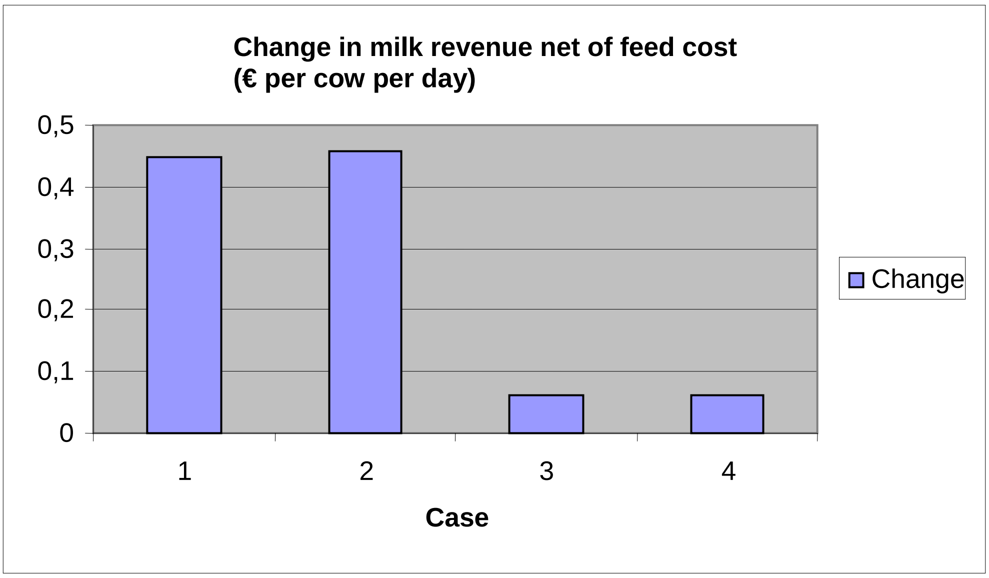


Figure 13. The change in daily milk revenue net of feed cost.

6.2.3 Replacement

A simulation of the free stall farm yields the same effects on replacement as on the Mix farm. The initial value for voluntary culling is slightly lower, implying that it does not account for as large a share of the total replacement rate. Hence, culling more closely follows the change in pregnancy rate. An increase in pregnancy rate causes a lower cull rate.

The cost of culling, the cost of a pregnant heifer net of the cull cow value, is 807 € which affects the results strongly. These changes range from 13 % in case two to 3 % in case four. Consequently the cost of recruitment per cow per year ranges widely. The net revenues of reduced replacement costs are 87 € in case one, 105 € in case two and 36€ and 23 € in case three and four respectively. As in the Mix farm case the cull rate follows the pregnancy rate with slight variations.

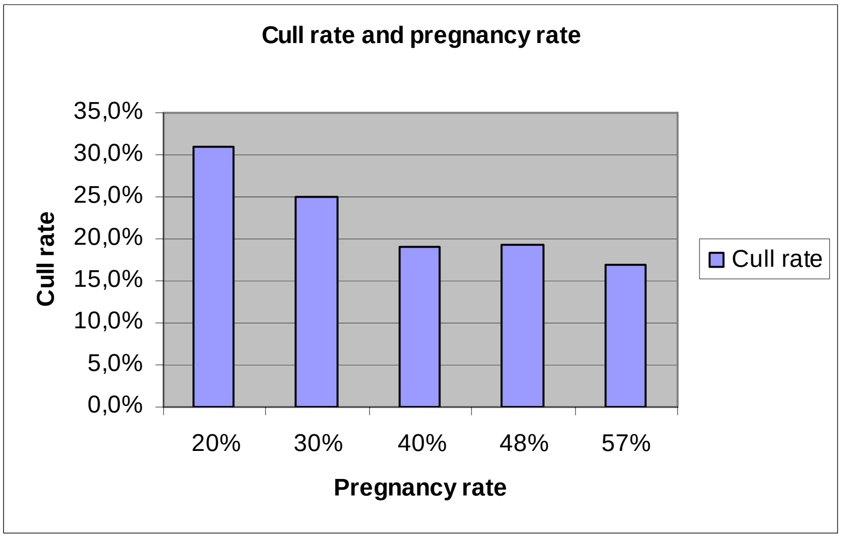


Figure 14. The relationship between pregnancy rate and total cull rate.

6.2.4 Breeding and calves

Breeding costs and calves contribute to a fairly small share of the economic gain origin from activity metering. In fact, in case of the free stall farm a negative value is obtained on the calf. The value of the calf is affected by a higher milk price affecting the feed cost. Feed costs, the expected cost of diseases net of the market value of the calf creating a cost per calf of 8,8 €. Despite the cost incurred by the calves a positive net effect is obtained when activity metering is used. The reason is that the number of calves decreases as the activity metering is used. The effect is due to decreased culling. Every replacement heifer brings a calf to the herd. As calving interval decreases it results in more calves, but the replacement rate is reduced thereby bringing fewer calves to the herd. Less recruitment heifers enter the herd when activity metering is introduced. However the change is relatively small, ranging from 1,97 € to 0,59 € per cow per year in the four cases. Hence calves have a marginal effect on the net revenue.

Breeding costs causes minor changes in net revenue when activity metering is used. However the change is positive and contributes to the net revenue of the investment. No pattern can be observed when comparing the four cases. The largest gain from reduced breeding costs are noted in case one and four, 2,26 € and 2,11 € per cow per year respectively.

6.3 Stochastic variations

Due to the stochastic elements of the simulation model the results vary. By simulating the same herd with the same settings twice results will diverge slightly. The stochastic nature of the model also generates varying results from one year to the next within the same simulation. The drawing of random numbers using a standard uniform distribution triggers the random events pregnancy and culling.

The stochastic elements of the model are Pregnancy Rate (PR) and Cull Rate (CR). PR and CR depend on the standard uniform distribution $F(y) = 1 / (b-a)$, $a \leq y \leq b$. Using the standard uniform distribution to generate random events causes the variations in the results.

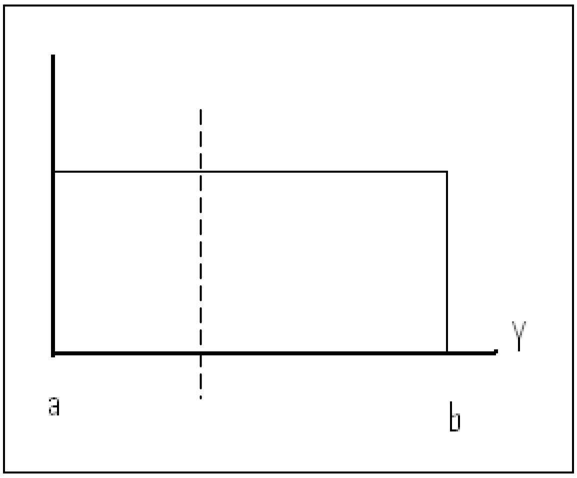


Figure 15. The standard uniform distribution $F(y) = 1 / (b-a)$, $a \leq y \leq b$. *The dotted line represents cull rate or pregnancy rate. Random numbers less then the cull- or pregnancy rate result in a cull or a pregnancy.*

As referred to above, culling and calving intervals are the two most important factors affecting the results. A rather small change in these variables causes the result to differ. Calving interval is determined by PR and culling is determined by CR and pregnancy rate. A low pregnancy rate causes increased culling due to infertility. As calving interval and culling are affected by the standard uniform distribution they tend to vary.

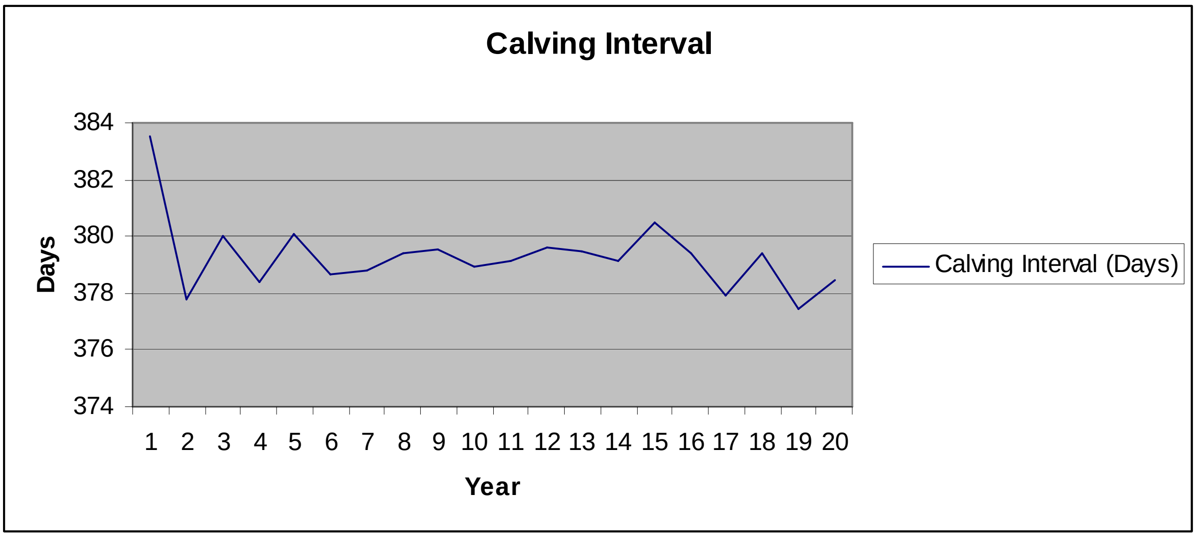


Figure 16. Changes in the calving interval due to the distribution of the random numbers around PR. Free Stall farm, 57% PR.

The calving interval is an effect of the pregnancy rate. The pregnancy rate determines the average speed at which the cows in the herd become pregnant. However, drawings of the random numbers affect when the individual cows became pregnant. The stochastic nature of the pregnancy rate thereby affects the length of the calving interval. Milk yield is an effect of the calving interval which also affects feed cost.

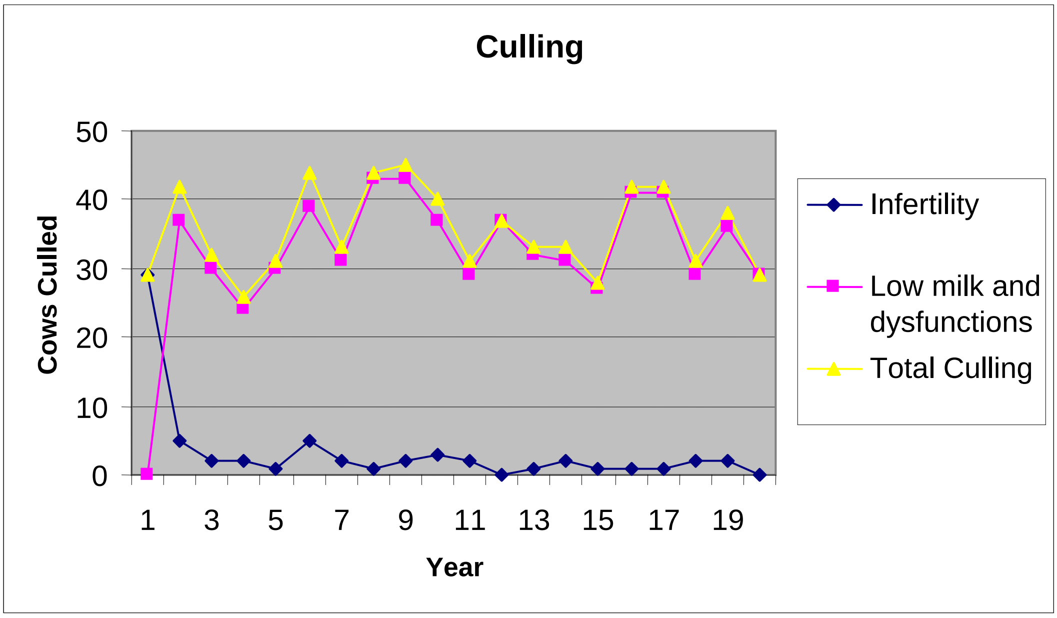


Figure 17. Culling varies due to the distribution of random numbers around PR and cull rate. Great Britain farm, 57% PR and 20% cull rate.

Culling is affected by the stochastic elements of the model in the same way as milk yield. The replacement cost may therefore vary and causes the results to diverge. As the analysis is based on one specific simulation of a herd over a 20 year time period for each unique case these variations explains results that doesn't follow the expected pattern in terms of herd performance.

The stochastic variations described result in differing net revenue shown in figure 18. The standard deviation of the net revenue is 29838, 2 €.

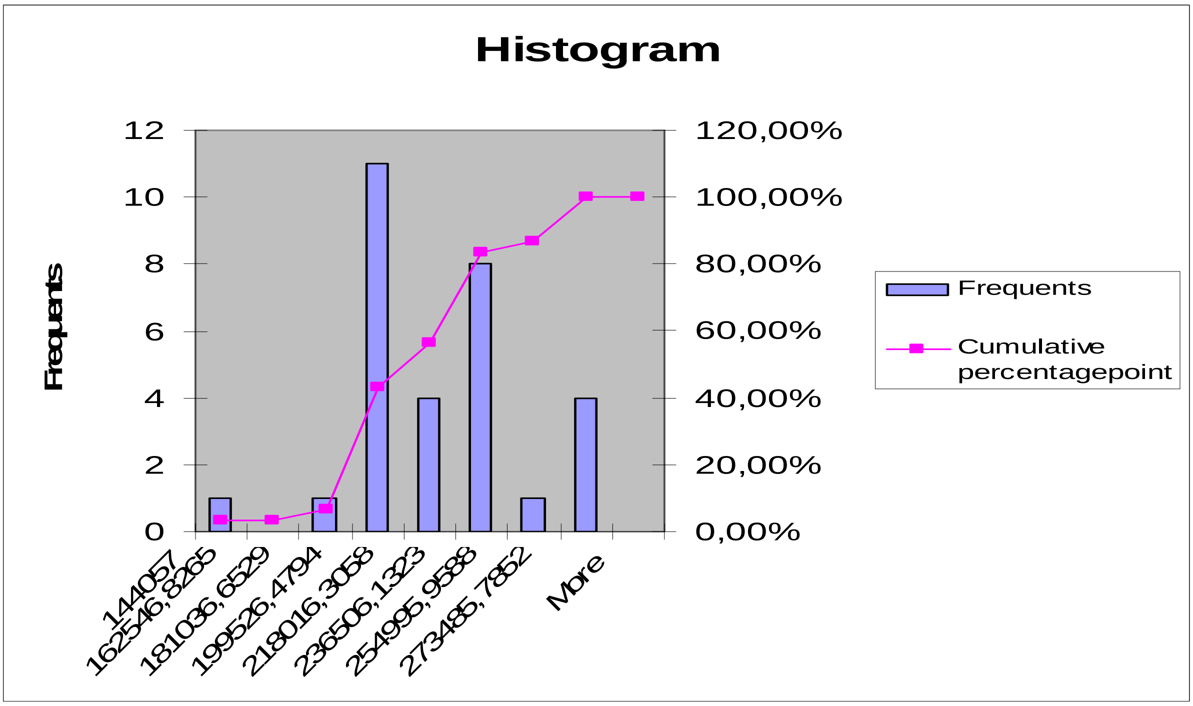


Figure 18. Histogram and sum curve describing the results from 30 simulations case Great Britain case two.

Table 6.3 Results from 30 simulations
Great Britain case two

N	Mean	Median	Variance	Std Dev
30	213846,8	208017,7	890318153	29838,2

Running the model simulation 30 times displays relatively steady results. Mean revenue is 213846 € with the mean of 208017 €. In practical use of the simulation program this spread of results should be considered. Results based on one single simulation are likely to display a value that diverges from the mean value.

7 Conclusions

The simulation model developed in this thesis has proven to be a functional tool when calculating the effects from introducing the new technology on the dairy farm. By using the two parameters heat detection rate (HDR) and conception rate (CR) the reproductive performance is quantified as pregnancy rate (PR), the speed at which cows become pregnant. The introduction of activity metering causes an improvement in these measures with subsequent other effects. The simulations reveal a decrease in calving interval and a decreased replacement rate as an effect of improved reproductive performance. The decrease in culling rate is due to the fact that fewer cows are culled due to infertility. Decreased culling causes an increase in the net revenue of the dairy farm. A decreased calving interval also increases milk yield per cow per day without a proportional increase in the feed cost. The change in milk revenue net of feed cost increases the annual net return of the activity meter as pregnancy rate increases. The simplicity of the model facilitates the understanding of the effects of increased reproductive performance. The measures milk yield, feed cost, reproduction cost, replacement costs and calves born provide a simple but reliable measure for revenue calculations. Comparing the farm performance with and without activity metering provides the net revenue from the new technology. The results differ in the two alternatives, the mix farm and the free stall farm. However, in both cases activity metering contributes to an increase in profitability. The analysis is carried out using four scenarios where initial reproductive performance is varied as well as the assumed increase in reproductive performance due to activity metering.

The results in the mix farm simulation and the free stall farm differ slightly. However they follow a similar pattern as the different cases are applied on each farm. As the farms differ in size, 150 cows on the mix farm and 400 on the free stall farm, the revenue is calculated on a per cow and year basis. A comparison between the two case farms and the four scenarios for the simulations on each farm, the net revenues varies but are positive in all cases.

Table 7.1 The revenue generated as activity metering is introduced.

Case PR (No AM / PR AM)	Revenue/cow/year Mix	Revenue/cow/year FS
1 (20% / 48%)	178 €	251 €
2 (20% / 40%)	172 €	258 €
3 (30% / 48%)	94 €	107 €
4 (40% / 57%)	8 €	70 €

The results displayed in table 7.1 summarize the results from the case farms. As the initial state of the pregnancy increases, revenues decrease. A farm with initial poor reproductive performance therefore benefits more then a farm that performs fairly well. Still, all cases gain in net revenue ranging from remarkable to satisfying.

The new technology causes a relatively substantial impact on net revenue which depends on two main effects:

1. The increase in pregnancy rate reduces the number of cows that are culled due to infertility.
2. A shorter calving interval improves the economic efficiency of milk production due to the form of the lactation curve and feed consumption.

These effects are discussed under two separate headings.

Breeding cost and calves have a rather small impact on the result and do not follow the same pattern as milk yield and replacement. The cost of breeding consists of the cost of semen, time spent on breeding and veterinary costs for pregnancy checks. As fertility improves the number of inseminations per pregnancy is reduced and should therefore decrease costs. However, improved fertility and a shorter calving interval result in a slight increase in the number of pregnancies per cow and year, causing increased costs of breeding per cow and year.

In terms of calves, milk price and veterinary costs causes a value of calves close to zero. Compared to the costs of replacement and the increase in milk yield the calf has a small impact on the net revenue unless its price increases. As replacement heifers bring calves to the herd an increase in culling slightly increases the number of calves born. The increase in the number of calves due to a shortened calving interval is offset by the reduction in calves born due to reduced culling.

7.1 Replacement

The impact of pregnancy rates on the economic result is clearly demonstrated by the introduction of automated estrus detection. As the difference in cull cow value and the price paid for a pregnant heifer widens a small change in cull rate generates a large gain in net revenue.

Table 7.2 The price of a cull as difference in the price of heifers and cull cow value

Case Farm	Price of heifer	Cull cow value	Difference
Mix	1159	379	780
Free stall	1087	280	807

As culling rates differ between the two case farms and the different scenarios, the cost of replacement is affected which contributes to a positive result. Based on table 7.1 a change in the cull rate of 10 % would result in a change of costs of 78 € in the mix case and 89,7 € in the free stall case. The mix farm is saving 100 € per cow per year in case one dropping to a increase in reproductive cost by 3 € per cow as culling rate increase by 0,5 % in case four. Having a wider span in the value of heifers and cull cows the free stall farm gains larger revenues as replacement is decreased. Case two having the largest gain in decreased cull rate saves 105 €, and 23 € in case four gaining the smallest change.

The replacement rate is also more affected when the initial pregnancy rate is low, which is the effect of poor initial reproductive performance. As the initial pregnancy rate increases the effects from increased reproductive efficiency decreases the gains due to lower culling. The cost of replacement is heavily affected by the initial reproductive performance of the herd but still the gains from increased performance due to activity metering are substantial.

7.2 Milk yield and feeding

The second large economic gain from activity metering origins from an increase in milk yield. The increase in milk yield is an effect of the form of the lactation curve. Peak in the early stages of the lactation and decline through out the rest of the period result in a positive effect on milk yield.

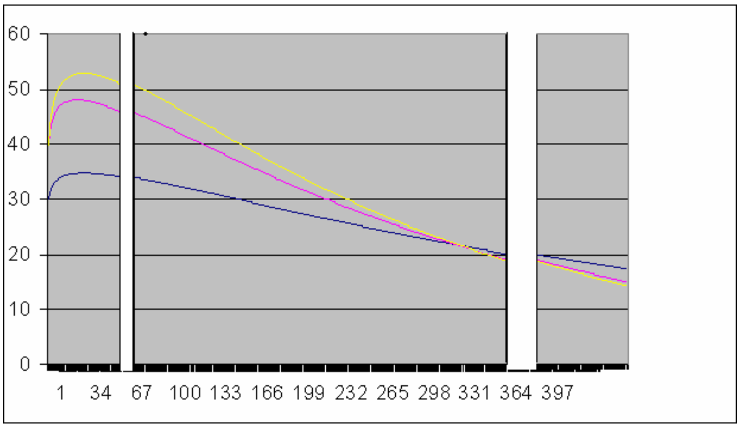


Figure 19. The effect of a shortened calving interval can be illustrated as a cut in the end of the lactation curve. The less productive end of the lactation is shortened which enables the cow to enter the more productive parts of the lactation more frequently.

As the lactation shortens the last, less productive phase is changed to the most productive, early part of the lactation. The effect from cutting the low yield part of the lactation increases average daily milk yield. As feeding does not correspond proportionally to increased milk yield, as shown in the analysis, the decreased calving interval is creating a positive relation of milk revenue net of feed cost.

Table 7.2 The difference in milk revenue net of feed cost.

Case	Free stall	Mix
1	0,448	0,271
2	0,457	0,239
3	0,062	0,129
4	0,062	0,046

Table 7,2 provides figures usable to calculate the annual milk minus feed revenue generated by the activity meter. Multiplying the figures by 365 days the total gain per cow per year is calculated for.

8 Discussions

The positive revenue from the investment is mainly explained by replacement and milk yield and feed cost. The measures are however simplified in some extent. Replacement tends to decrease as fertility increases. As mentioned in the background culling due to low milk yield sometimes have to be reduced due to culling for infertility in order to utilize the full capacity of the dairy barn. Introducing activity metering in the model, fewer cows are culled as fertility is improved. Assuming that the farm initially culls a large number of cows due to infertility, activity metering would allow herd management to expand culling of low yielding cows in order to increase herd average milk yield. The simulations may therefore overestimate the decrease in culling. In the cases where initial reproductive efficiency is low the revenue from decreased culling may be overestimated. However the effects of increased milk yield due to genetic improvement of the herd would be difficult to model within the framework of this analysis

Milk yield in the model is based on a pregnant cow average milk yield. Milk yield follows the original lactation curve (Strandberg, 1989) with an effect of pregnancy diminishing daily yield in the latter part of the lactation. The yield of the cow due to culling is difficult to estimate because of several reasons. The cause of the culling affects the average yield of the cow culled. Cows that are to be culled because of infertility would have a flatter shape of their lactation curves compared to pregnant cows. Their yield is thereby underestimated. However, low yielding cows would not produce the same quantity as the average cow. Cows culled due to decease in the early stages of the lactation would affect the average yield of the herd as their average daily milk yield would be based on the early, high yielding part of the lactation. The time a cull cow is kept in the herd before she is eventually sold varies due to the cause of the culling, capacity utilization of the herd, the yield of the cow and so on. The method used for milk yield calculation must therefore be regarded as a simplification of the problem.

Due to the complicity of the problem the model is a simplification. The calculations are based on assumptions that are very complicated when analyzed in detail. However, the result reveals that the activity meter system increases the dairy farm profitability. The difference in milk yield and feed cost and the impact on replacement costs create a multiplier effect on the profit of the dairy herd.

8.1 Suggestions for future research

Being a simplification of a rather complex problem the study provides opportunities to develop the model. More variables can be added and currently used parameters be further developed. Time spent on heat detection is not a part of the analysis. Farmers opinions of time saved vary and were not reliable enough for this study. Time saved could easily be entered into the model if reliable data could be found.

Bibliography

Literature and publications

Esslemont R.J. 2003. *The cost of poor fertility and what to do about reducing them*. Cattle Practice, Vol II Part 4

De Mol R.M 2000. *Automated detection of oestrus and mastitis in dairy cows*. Ponsen & Looijen bv, Wageningen (ISBN 90-5406-182-0)

De Vries A., van Leeuwen J., Thatcher W.W. 2006. *Economics of improved reproductive performance in dairy cattle*. University of Florida IFAS Exension. Florida

Engström A, Jafner B.M., 1997. *Mjölkkor*. LTs Förlag, Stockholm (ISBN 91-36-03321-9)

Esslemont R.J.j., Kossaibati M.A. 2002. *The cost of disease and poor fertility in dairy herds*. DAISY Report No 5.

Jaghannatha S, Keown J.F., van Vleck L.D.. 1998. *Estimation of relative economic value for herd life of dairy cattle from profile equations*. J DairySci, 81:1702-1708

Garnsworthy P.C. 2005. *Calf and heifer rearing*. Nottingham University Press, Nottingham (ISBN 1-904761-22-4)

Hemme T, Deeken E et al. 2005. *IFCN Dairy Report 2005*, International Farm Comparison Network, Global Farm Gbr, Braunschweig

Instruction Book ALPRO ver 6.50/DeLaval activity meter system, DeLaval Box 39, Se – 14721 Tumba, Sweden

Hollman F.J., Shumway C.R., Blake R.W., Schwart R.B. & Sudweeks E.M. 1984. Economic value of days open for Holstein cows of alternative milk yields with varying calving intervals. *Journal of Dairy Science* 67, 636 - 643

Horn,H.H.van., Wilcox, C.J. 1992. *Large dairy herd management.* Amarican Dairy Science Association. Champaign (ISBN 0-9634491-0-9)

Murray R & Giudice P. 2006. *Heat detection analysis using the DeLaval Activity Meter in Grassland systems*. Province of Buenos Aires, Argentina

Nebel R.L & McGilliard M.L 1993. Interactions of high milk yield and reproductive performance of dairy cows. *Journal of Dairy Science* 76, 3257 - 3268.

Rougor C.W. 1999. *Management, milk production level and economic performance.* Ponsen & Looijen bv. Wageningen (ISBN 90-5485-973-3)

Rudolf J.F., William j.W. 1996. *Statistical methods*, Academic Press INC, San Diego (ISBN 0-12-267470-7)

Swensson C. 1998. *A simulation study of the effects from varying the time of first service on the economic output from a dairy herd with a milk quota.* Swedish Journal of Agricultural Research 1998, v. 28(4), p. 189-196

Van Asseldonk M.A.P.M 1999. *Economic evaluation of information technology applications on dairy farms*. Cip – Data Koninklijke Bibliotheek, Haag (ISBN 90-5808-006-4)

Østergaard S. 2004. *SimHerd PC programmes for simulation and analysis of production and health in the dairy herd*. Danish Institute of Agricultural Science, Department of Animal Health and Welfare, Research Centre Foulum, P.O. Box 50, DK-8830 Tjele.

Internet

Eurostat. 2007-02-27
http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,39140985&_dad=portal&_schema=PORTAL&screen=detailref&language=en&product=EU_shorties&root=EU_shorties/shorties/euro_cp/cp000

Finansportalen. 2007-02-27
http://www.finansportalen.se/

Personal messages

Per Arnesson. *Veterinary, Skara Semin*, Telephone 2007-02-28

Ann Lindberg, *Swedish dairy association*, E-mail 2007-03-05

Pris: 100:- (exkl moms)

Tryck: SLU, Institutionen för ekonomi, Uppsala 2007.

Distribution:

Sveriges lantbruksuniversitet	Swedish University of Agricultural Sciences
Institutionen för ekonomi	Department of Economics
Box 7013	P.O. Box 7013
750 07 Uppsala	SE-750 07 Uppsala, Sweden
Tel 018-67 2165	Fax + 46 18 673502