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MSc Thesis Business Economics Group

Association between operational KPIs and milk revenue on dairy farms

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Student: Adrie de Vos 900117-905-050

Supervisor: Dr. Ir. W. Steeneveld

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Preface

This thesis report is part of my study MSc Business Economics at Wageningen University. This study was commisioned by Agis Automatisering BV. Objective of this study was to get an economic expression of the most important KPIs. An additional objective of this project was to identify the potential of CowManager in creating new KPIs by new available information.
Since the start this subject has been an interesting challenge. Therefore, thanks go out to Gerard Griffioen for the awarding of the project. I want to thank Maarten-Jan van Fulpen for his supervision and his helpful different point of view. Also many thanks go out to Wilma Steeneveld for the great supervision and good collaboration.

Adrie de Vos
Wageningen, May 2014

Summary

Many farms are using aware or unaware Key Performance Indicators (KPIs), such as milk production, somatic cell count and calving interval. But all farms are using a different sets of KPIs. It's however not yet known which KPIs can best be used to maximize milk revenue. The objective of this study was to create a shortlist of KPIs that have the most influence on milk revenue. This shortlist can help farmers to decide which KPIs to manage on. To fulfil this objective a few specific objectives are made. First, there will be inventoried which KPIs currently exists, done in the literature study. Secondly, an analysis will be done on KPIs and their predictive relationship towards milk revenue. For the analysis not only existing KPIs will be taken into account, also new KPIs are included.

In a literature study an inventory was made to gather all currently existing KPIs. All KPIs were gathered which were measured on cow level and fitted the four categories: fertility, health, feeding and economy. For all KPIs a definition, effect of/on other KPIs and the economic effect is given.

Individual cow data was available out of two management programs, Dairy Comp 305 and CowManager, of two American dairy farms. With these data two analyses were performed. The first analysis is focussed on the effect of health KPIs on milk revenue in the start of the lactation (first 100 days). KPIs taken into account for this analysis are on health, feeding and economy. Data for the first analysis included information on 916 cows. The second analysis is investigating the effect of all available KPIs on milk revenue in the first 305 days of lactation. This analysis takes KPIs into account on fertility, health, feeding and economy. Data for the second analysis included information on 458 cows.

Both sets of data were analysed by a generalized linear model, using a backward stepwise procedure. The first analysis gave as a result 11 variables which have a significant predictive effect on milk revenue. In the second analysis, 9 variables came out as the variables with the most predictive power on milk revenue. In both analyses farm and parity had the most influence on milk revenue, while farm must be seen as a correction variable. Finally, a shortlist was made with the 6 KPIs that have the most effect on milk revenue. These KPIs are:

1. Parity (age)
2. Milk content (fat and protein percentage)
3. Number of metritis treatments
4. Amount of hours sick (pre- and post-partum)
5. Amount of ruminating minutes
6. Amount of eating minutes

These KPIs are suitable to manage on. The last three of these variables are made available by the SensOor of Agis Automatisering, and even more new KPIs could be created on information of the SensOor. Further research on new KPIs should focus on the transition period of cows and on feed intake on base of eating time.

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1. Introduction

Over the last decades many Key Performance Indicators (KPIs) were developed for dairy farms. KPIs represent a set of measures focusing on those aspects of organizational performance that are the most critical for the present and future success of the organization (Parmenter, 2010). An example of a KPI is the pregnancy rate on dairy farms, which informs dairy farmers about the actual fertility performance. KPIs help organizations and firms to set their objectives and measure its progress. KPIs must be quantifiable and reflect the objectives the organization set. When KPIs aren't quantifiable they won't be measurable and not useable as a KPI. Together with the objectives also targets for the KPIs must be set, for targets and objectives counts the same, the definition shouldn't change from year to year. The targets and objectives should only be changed when the goal nearly is reached (Reh, 2013). The optimal amount of KPIs is questionable, and according to Miller (1956) a person can't handle more than about 7 different information sources without making any mistakes. More KPIs will cause confusion by the user and less KPIs will not cover all information. However, new techniques are developed, and so are new KPIs. Factors which earlier couldn't be measured or weren't available for traditional farms, come available now. The amount of KPIs is still rising.
Every farmer has its own set of KPIs to manage on. Assumed can be that all farmers in the end have the same main objective, maximizing profit. Which KPIs fits the best to this objective is not very clear, due to the diversity in KPIs. Therefore, it is important that only the most appropriate KPIs are presented to the farmer. No studies were found on the relationship between KPIs and profit/milk revenue. However, studies were found on health disorders and revenue on normative data (Østergaard et al., 2003; Bruijnis et al., 2010). Also studies were found on single KPIs and their relation to revenue or profit (Auldist, 1998; Barret, 2002; Duffield, 2000; Eicker, 1995). But studies which investigated the relationship between multiple KPIs and milk revenue weren't found.

The objective of this study is to create a shortlist of KPIs that have the most influence on milk revenue. This shortlist can help farmers to decide which KPIs to manage on. To fulfil this objective a few specific objectives are made. First, there will be inventoried which KPIs currently exists, done in the literature study. Secondly, an analysis will be done on KPIs and their predictive relationship towards milk revenue. Finally, there is an analysis on new created KPIs and their relation with milk revenue. These analyses will be based on data of 2 US dairy farms.

2. Literature study

In the past 100 years many things have changed on dairy farms. From milking by hand to robotic milking and from earning a living with two cows to keep over 1.000 cows in the US and producing as efficient as possible. Producing as efficient as possible is influenced by several factors. Automation (automatic milking, feeding by tractor) made it possible to take care of more cows with less labour and changes in management (way of keeping cows, changes in feed ration) created a great increase in milk production.

Measuring performance and movement in performance on dairy farms became very important. This measuring is often done by Key Performance Indicators (KPIs). KPI's are previously defined as a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization (Parmenter, 2011). It is hard to create KPIs which measures performance correctly and gives the right information to the decision maker. Therefore, good KPIs should meet some conditions, which will reduce the risk for bad KPIs (Anderson, 1996b; El-Mashaleh, 2007; Airforce, 1991). These conditions include:

- Acceptable
- Meaningful to industry
- Easily understood
- Repeatable
- Show a trend over time
- Suitable
- Feasible
- Aligned
- Timely
- Actionable

Most important in the end is that there aren't too much KPIs, people just can handle a certain amount of KPIs in a good way (Miller, 1956).

This literature study is a review on the current KPIs used on dairy farms. Main focus is on the KPIs used in the US, the Netherlands, the UK and Canada. KPIs will be classified into the categories Fertility, Health, Feeding and Economy. Only KPIs will be selected which are cow related and measure performance on cow level. However, most of these KPIs will finally be used and shown on herd level. For all KPIs a definition will be given, as well as the influence on other KPIs and the economic effect. All economic effects are expressed in Dollars. For Euro's to Dollars a currency of 1.3682 is used, the currency used of Pounds to Dollars is 0.8333. After the literature study, the KPIs will be compared and analyzed on cow level.

2.1 Fertility KPIs

Reproductive performance of dairy cows has declined in the past 2 generations (Lucy, 2001). According to Weigel (2006) this is associated with management practices, housing and milk production. With help of KPIs decreasing performance can potentially be detected and resolved. For fertility the following KPIs are found and elaborated:

- Heat detection rate
- Conception rate
- Pregnancy rate
- Voluntary waiting period
- Number of days open
- Calving interval
- Service rate
- Reproductive culling rate
- Non return rate

Heat detection rate

Heat detection rate can be calculated by dividing the number of cows inseminated over a 21 day period by the number of cows that could have been served that period (Infodairy, 2013). Averages of heat detection weren't found or were unreliable.

According to Berglund (2008) plays heat detection a considerable role, though an economic value is not mentioned in that study. Other studies did found an economic value for heat detection rate. Plaizier et al. (1998) found that the heat detection rate is valued varying from $2.48 to $19.29 per % increase per cow per year dependent on the re-breeding program. De Vries and Conlin (2003) found an effect on net revenue per percent increase from $0.69 to $2.38, dependent on the level of the detection rate. It was also mentioned that an improvement of the heat detection rate from 30% to 50% reduced the economic loss with $72.91 per cow per year, while an improvement from 50% to 70% reduced the economic loss with $15.32 per cow per year (Inchaisri et al., 2010).

Conception rate

The conception rate is frequently used as an indicator for fertility (Chebel, 2004; Rounsaville, 1979). The conception rate can be defined in two ways, per service and per all services. The conception rate per service is calculated as the number of pregnant cows after service *n* divided by the sum of the number of pregnant cows and cows with unknown pregnancy status after service *n*. The conception rate per all services is calculated by dividing the total pregnant cows by the total amount of services minus the number of unknown cows.

Over the last 50 years heifers in the US have almost reached the practical optimal conception rate of 65%. The first service conception rate for lactating cows has decreased in this period from 60 to 40% (Nebel, 2002).

The economic consequences of a higher conception rate are investigated by Van Arendonk and Dijkhuizen (1985) and Inchaisri et al. (2010). Van Arendonk and Dijkhuizen (1985) found that every % increase in conception rate had a value of $1.67. Inchaisri et al. (2010) found that an increase from 30% to 50% in conception rate reduced the economic loss with $103.35 per cow per year, while an increase from 50% to 70% in conception rate reduced the economic loss with $22.83 per cow per year.

Pregnancy rate

Pregnancy rate is calculated by multiplying heat detection rate with conception rate (Infodairy, 2013). Therefore, only a low heat detection rate and/or low conception rate will cause a low pregnancy rate. Desirable is a pregnancy rate as high as possible, but a good goal is a pregnancy rate of 35% (Infodairy, 2013), while pregnancy rates often only reach 15% (Hunt, 2013).

The pregnancy rate has great influence on days open and economic returns associated with production (Ferguson, 2013). An increasing pregnancy rate will reduce days open, besides that it also will increase the revenue per cow. Also the amount of culled cows will be lower with a higher pregnancy rate. A decreasing pregnancy rate will reduce the daily milk yield per cow.

Each extra percent increase in pregnancy rate will gain $35, so an increase from 14% to 22% will gain $280 (Hunt, 2013) per cow.

Voluntary waiting period

The voluntary waiting period (VWP) is defined as the target number of days post-partum, after which the cow will be inseminated. In contrast with the other KPIs is this KPI a key management decision (Miller, 2007) and not an outcome of the reproductive performance. According to Inchaisri et al. (2011) does the optimal VWP vary among farms and cows. Fetrow et al. (1997) recommends a VWP of at least 45 to 60 days. The VWP period has great influence on number of days open and thereby calving interval. Another indicator which is influenced by the VWP is conception rate, which is expected to increase when days in milk increases.

According to Sørensen (2003) has the VWP economic consequences. A longer VWP means no difference in conception rate, a higher pregnancy rate, but a lower herd value. Herds with an observed VWP of 50 to 59 days had per cow a $31 higher value than herds with an observed VWP of >70 days.

Number of days open

The number of days open is the interval between calving and successful artificial insemination (Bousquet, 2004). It’s called one of the most important indicators for reproductive performance, and is influenced by the voluntary waiting period, heat detection rate and conception rate (Bousquet, 2004).

The duration of a pregnancy is quite constant, therefore the costs of one extra day open is similar to the costs of one extra day calving interval. Several studies investigated the costs of one extra day calving interval, and values ranged between $0.08 and $4.04 (Groenendaal et al., 2004; Inchaisri et al., 2010; Meadows et al., 2005; de Vries and Conlin, 2003; Veerkamp et al., 2002; Plaizier et al., 1997).

Calving Interval

Calving interval is defined as the number of days between two successive calvings, and is frequently used as an indicator for fertility on dairy farms (Robinson, 2010; Bousquet, 2004). In the Netherlands, the average calving interval is 417 days in 2011 (CRV, 2012), while in the US the average calving interval is 409 days for Holstein cows in 2011 (Wright). Stevenson (2007) regarded a calving interval of 12 to 13 months as economical optimal. It is found that a higher calving interval results in a lower milk production per cow per year and less calves per year (Esslemont, 2001). Reasons for a high calving interval are a low conception rate (Inchaisri et al., 2010), a low heat detection rate and a long voluntary waiting period (Inchaisri et al., 2011). The economic consequences of a higher calving interval are investigated in several studies, and already mentioned at the KPI Number of days open.

Service rate

The service rate gives the amount of inseminations needed for a pregnancy, which can be expressed on cow level and on herd level. In the last 14 years the service rate in the Spanish dairy herd has gone up from 1.7 inseminations to 2.0 inseminations (González-Recio et al., 2004). According to González-Recio et al. (2004) are the costs of every extra insemination $67.33 per cow per year. Although the cows that needed more inseminations produced more milk per lactation, they had a higher culling risk and a lower lifetime production, which reduced the profit.

Reproductive culling rate

The reproductive culling rate is the percentage of cows culled which didn't get pregnant within a certain amount of inseminations. This maximum amount of insemination is set by the farmer on beforehand. Therefore, the reproductive culling rate is part of involuntary culling, what means culling for a reason which wasn't the farmers choice (Chiumia et al., 2013).

The reproductive culling rate is of great influence on reproductive performance. The reproductive culling rate together with calving interval and pregnancy rate is a good indicator for fertility (Esslemont, 1992). In a study of Brickell and Wathes (2011) on culling decision till 3rd lactation 33% of the cows were culled due to infertility. Moussavi (2008) found that 25.6% of the total culled cows were culled due to fertility problems. Costs of a change of 1% in reproductive culling rate weren't found.

Non return rate

The non-return rate measures which percentage of cows is not re-inseminated within a certain period, mostly 56 days after last insemination (Leblanc, 2010). Cows without a re-insemination are assumed to be pregnant. The non-return rate is often overestimating the pregnancy because cows that doesn't show heat aren't by definition pregnant (Leblanc, 2010). On the other hand, numbers like inseminations are widely available and easy to measure. The target value in "Veemanager" (a Dutch management system by CRV) is set at 60%, but higher is better. On this KPI no economic number were found.

2.2 Health

Every farmer wants a sustainable cow, where a sustainable cow is seen as a cow with a good milk production and few production problems. Volling et al. (2010) suggests that there is a relationship between health of the cow and the economic performance of the herd.
First an overview of KPIs will be given which gives an impression on the prevalence of the most common diseases. In the second part other health related KPIs are elaborated, these are the following:

- Incidence indicators
    - Clinical Mastitis
    - Metritis
    - Clinical Lameness
    - Hypocalcemia
    - Ketosis
    - Ruminal acidosis
    - Abomasum dislocation
- Longevity
- Somatic cell count
- Culling rate
- Animal daily dose

Incidence indicators
A way to keep track on health disorders is tracking the incidence rates. By setting periods and averages a deviation can early be detected and great economic losses can be prevented. Examples of KPIs which measures amount (is #) of common health disorders in dairy cows are the following:

Clinical Mastitis
Clinical Mastitis is an inflammation of one or more quarters of the udder of a cow. The inflammation can be recognized by a warmer and swollen quarter of the udder and the milk out of this quarter can have small clots. Mastitis is one of the most common and therefore also one of the most costly diseases in the dairy sector. These costs are often underestimated while the decrease in milk production and the risk on culling are not directly visible (Hogeveen et al., 2011).
The appearing of mastitis is highly influenced by management, among other treatment of the disease, dry cow therapy and prevention of transmission of infection (Halasa et al., 2007). According to Halasa et al. (2007) the costs for clinical mastitis were up to $393 per cow per year. In a study of Huijps et al. (2008) estimates for clinical mastitis came to $287 per average clinical mastitis case, varying from $322 in the first month post-partum to $224 in the last part of the lactation.

Metritis
Metritis can be distinguished into two kinds, metritis which is an inflammation of the endometrium, glandular tissues and muscle layers, and endometritis which is just an inflammation of the endometrium and the underlying glandular tissues (Manspeaker, 2011).
A heavy calving or retained placenta are often called as causes of metritis (Curtis et al., 1985; Kaneene and Miller, 1995; Bruun et al., 2002). Effects of metritis are a reduced milk production and problems with reproduction (Opsomer et al., 2000; Melendez et al., 2004). According to Lewis (1997) the amount of cows with metritis within a herd could go up to 40%, in a study of Miller and Dorn (1990) 32% of the cows got metritis. According to Bartlett (1986) are the average costs of metritis $106 per cow per lactation, other studies on the economic impact of metritis weren't found.

Clinical Lameness
The amount of lame cows includes actually only the cows with clinical foot disorders. Clinical lameness is a collective noun for foot disorders which are causing lameness. The four most common disorders are sole ulcers, white line disease, digital dermatitis and interdigital necrobacillosis (Blowey, 2005).
In Northern Ireland the average herd had 16% lame cows per year, the average treatment for a lame cow cost $204 (Enterprise, 2006). In a study of Espejo et al. (2006) was the prevalence of clinical lameness in Minnesota dairy herds 24.6%. Starting with a prevalence of 12.8% in first-lactation cows increasing each lactation with 8%. According to Bruijnis et al. (2010) an average lameness will cause a loss of $95 per cow.

Hypocalcemia
Hypocalcemia is also known as milk fever. Symptoms of this health disorder are low appetite, tetany but most of all the downer cow syndrome. Just after partus the cow starts to produce milk, the first milk contains a lot of calcium, therefore the cows loses a high amount of calcium. Due to low mobilization of calcium out of the bones and a low feed intake there is a shortage of calcium, this will cause that the cow isn't able to stand up (Horst et al., 1997).
Risk on hypocalcemia is influenced by breed, age and diet. The breeds Swedish red and white and Jerseys and older cows are more susceptible for milk fever. Also the ration during the dry period is of great influence. A low amount of calcium during this period is seen as optimal. The average cost of a cow with hypocalcemia is estimated at $334, included in this number is the treatment and the estimated production losses (Guard, 1996).

Ketosis
Ketosis is a health disorder which occurs in the start of a lactation. Clinical ketosis is caused by a combination of appetite limitation and a too high milk production, which causes a negative energy balance. Effects of ketosis are a diminished appetite, decreased milk production, loss of weight, hypoglycemia and hyperketonemia (Baird, 1982). Subclinical ketosis has the same effects but in a lesser extent, and is therefore often not noticed.
Incidence rates of subclinical ketosis were ranging from 40% to 60% in several studies (Emery et al., 1964; Simensen et al., 1990; Duffield et al., 1998). In another study of Duffield (2000) clinical ketosis was found in 2% to 15% of the herd. Costs of an average ketosis wasn't found.

Ruminal acidosis
Ruminal acidosis can be divided in clinical and subclinical acidosis. When the PH in the rumen is between 5.2 and 5.6 it is called subclinical ruminal acidosis, and a PH below 5.2 is called clinical acidosis. Subclinical acidosis can be recognized by low milk fat, thin manure, laminitis and sole ulcers. Cows with clinical acidosis will hardly eat anything and are lackadaisical, therefore cows with clinical acidosis will lie down a lot (Owens et al., 1998).
Nocek (1997) found several reasons causing (clinical and subclinical) ruminal acidosis. The ration form pre- to post-partum differs a lot. The ration drops in neutral detergent fiber (NDF) to a NDF poor ration and the amount of quick fermentable carbohydrates rises every day. The cow can't adapt sufficiently to this ration and has high risk for ruminal acidosis.
According to Maulfair et al. (2013) a subclinical acidosis can cost up to $475 per cow in loss of milk production only. In the same study all fresh cows were tested, and more than 20% of the cows had subclinical acidosis. Costs and prevalence of clinical acidosis weren't found.

Abomasum dislocation
The abomasum dislocation often occurs in the first weeks postpartum. A slow increase in feed intake and a quickly decreasing forage to concentrate intake ratio in the first weeks after postpartum are great risk factors for migration of the abomasum (Shaver, 1997).
The first costs of a dislocated abomasum are already the treatment costs, which are between $100 and $200 per case. Despite of that, 10% needs to be culled and average production loss is 350 kg milk in the following month (Eicker, 1995). Averages of the prevalence of this health disorder weren't found.

Longevity
With longevity the productive life or the age of culling is meant. Therefore these KPIs are expressed in amount of lactations and/or age. In the study of Pritchard et al. (2013) dairy cows in the United Kingdom reached the age of 6.8 (in 2009) with 4.3 productive years and 3.6 calvings. For example, in the Netherlands cows calved in 2009 on average 3.5 times. Longevity is one of the most determining traits on cow profitability. It practices great influence on replacement, higher intensity of dam selection and the amount of older cows (Essl, 1998; Vanraden and Wiggans, 1995).
(Beaudry, 1988) found that first lactation performance was more correlated with per day profit than with total lifetime profit. However, Norman and Van Vleck (1972) found that milk yield was the indicator with the highest correlation to lifetime milk. In their research milk fat had the highest correlation with number of lactations.

Somatic cell count
The somatic cell count (SCC) is a KPI used on dairy farms as a measure for udder health. An udder inflammation causes a deviated higher amount of cells and is therefore a good indicator (El-Tahawy and El-Far, 2010). A healthy udder is assumed to be between 50,000 and 100,000 cells/ml of milk, and 200,000 cells/ml is considered as a threshold between healthy and diseased (Fetherston, 2001; Barret, 2002). Cows with a SCC above 200,000 cells can be divided in cows with clinical and subclinical mastitis. Difference between clinical and subclinical is the appearance of the milk and the udder, which are described in *#clinical mastitis*. Every time a cow exceeds the 200,000 cells/ml gets counted and is called #increased SCC. By the end of the lactation perfectly can be seen how many times the milk exceeded in SCC. High somatic cell count has direct negative influence on milk yield, fat and casein content (Auldist, 1998; Barret, 2002).
Howard (1991) and Rougoor et al. (1999) concluded that SCC also could be used as a selection tool. With regard to the economics there can be chosen to treat or cull the cow with high SCC, for cows in late lactation there can also be chosen for drying off (Nizamlioglu, 1991; Anderson, 1996a). According to Steeneveld et al (2007) the average costs of a cow with subclinical mastitis are $149, while treating the cow will cost the farmer $164. However, not treating the cow creates the risk of high costs for cows with chronic subclinical mastitis.

Culling rate
In many studies culling is divided into voluntary culling and involuntary culling. Voluntary culling is culling with economic reasons, for example low production. Involuntary culling is culling due to health disorders or death (Dohoo, 1993). The USDA Animal and Plant Health Inspection Service (2002) classified the main reasons for culling. With 27% was mastitis the most important reason for culling, followed by reproductive problems with 26%. Poor production had a smaller share in the reasons for culling with 19%, lameness had only 16% share in the reasons for culling. Culling of cows can improve the performance by replacing sick or non-pregnant cows by higher producing cows, often heifers. Culling rates in dairy farms vary between 20 till 35% (Olechnowicz, 2011).

Animal daily dose

The animal daily dose gives the amount of average days a cow was treated with antibiotics per year, and thus illustrates the amount of antibiotics used. Animal daily dose is calculated by dividing the sum of all antibiotic used by total animal days that year. Within this calculation young stock is taken into account.

Animal daily dose is introduced in 2011 in the Netherlands and is used to decrease the use of antibiotics and with that the resistance to antibiotics in bacteria. There are three levels, the target level, the attention level and the action level. The attention level starts at the median of the animal daily dose, the action level starts at the 75 percentile. A farm who has an animal daily dose which is in the action level is supposed to take action and lower his antibiotic use, in the attention level farmers are only advised to take action (diergeneesmiddellen, 2013). Averages of antibiotic use aren't officially published, it is also made difficult by a change in the way of calculation. In the autumn of 2013 the average use in the Netherlands was 2.84 animal daily dose according the new way of calculating (Medirund.nl, 2013).

2.3 Feeding

Feeding is on dairy farms one of the largest costs, and a huge factor determining performance. Feeding is directly related to many health disorders and therefore interesting to measure per individual cow. New techniques can be helpful for the way of measuring the amount of feed intake, before this could only be done at test farms. This individual measuring can also be used for the following KPIs:

- Feed Intake
- Feed efficiency
- Body weight
- Energy balance

Feed intake

Measuring feed intake in dairy can be expressed in several ways. Most simple is the amount of kg feed taken in per cow per day, which is of good use for comparing feed intake within a herd. For comparing with other herds the feed intake has to be corrected for dry matter, which results in dry matter intake. Another way of measuring feed intake is counting the energetic content intake. Energy intake can be calculated by multiplying dry matter intake with the average energy content of the ration. Total energy intake can be important for creating the energy balance.

However measuring feed intake per individual cow before only could be done at test farms, it always have been an essential record for feed efficiency. New techniques are hopeful in developing an easy way of measuring individual feed intake.

Gravert (1985) assumed that capacity of the digestive tract increased linearly with cow size, and maintenance requirements increases with weight. Therefore, big cows would be better than smaller cows. However, for the absorption of nutrients the surface area of the digestive tract is much more important than the volume, so feed intake will increase with larger cows, but feed efficiency will decrease. Another cause what has great influence on feed intake is health status, in cows with a health disorder feed intake can be reduced for several days (Gravert, 1985).

Feed efficiency

Feed efficiency is the ratio between milk yield and energy intake, wherein the amount of milk per kg dry matter is expressed. Feed efficiency is an important indicator for efficient production, though it's part of it. To conclude with certainty if the production efficiency is high there must be sight on energy balance of the individual cows and the production traits (Simm et al., 1987).

Because feed efficiency has great influence on production efficiency there have been many studies on this subject. Van Arendonk et al. (1991) and Vallimont et al. (2011) found in their studies that feed efficiency had a heritability of 0.14 and 0.37, respectively. It was also found that there was a negative correlation between feed efficiency and body condition score of 0.70 (Spurlock et al., 2012).

There are also a few studies (Grieve et al., 1976; Custodio et al., 1983) that suggests that high feed efficiency is caused by higher degree of body tissue catabolism and dilution of maintenance and not due to better utilization of feed. They even suggests that the cows with high feed efficiency lose their advantage in a low input system (Veerkamp et al., 1994).

According to Gravert (1985) can feed efficiency be improved by breeding for a higher milk yield. However, a higher milk yield will cause a higher energy deficiency in the early weeks of the lactation, and will therefore be a burden for the cow.

Body weight

Body weight of dairy cows can be used to detect health disorders. The cows are automatically weighted after milking and a decreasing, or in high producing cows a higher than normal decreasing body weight, are signs of a health disorder.

A higher body weight will cause a lower feed efficiency because of the maintenance needed. The high production of larger cows is still a reason why they keep breeding on cows with a higher body weight. Body weight is also related to cow size, body condition score and to energy balance, but breeding on this traits is not directly improving feed efficiency. An improving growth rate in heifers is increasing feed efficiency. Heifers which are earlier well-grown can calve and start producing sooner (VanRaden, 2004).

Energy balance

The energy balance is the energy intake subtracted by energy expenditure for lactation, growth, reproduction and maintenance. When this balance is negative the cow is using more energy than is taken in. In that case the cow is mobilizing energy reserves from body tissue. Besides that a cow with a negative energy balance drops in body condition has it a lot of unfavorable effects. A negative energy balance has influence on reproductive performance, metabolic imbalance and other health conditions in high-producing dairy cows (Pryce et al., 2001; Veerkamp et al., 2001; Oltenacu and Broom, 2010).

High producing dairy cows reaches in the early stage of the lactation often in a negative energy balance. At already the 4th week postpartum a dairy cow reaches the peak in daily milk yield, while the feed intake reaches its maximum not earlier than week 10 to 12 postpartum. This gap in energy provision causes a higher feed efficiency in the early stage of the lactation (Gravert, 1985).

2.4 Economy

In this category the economic KPIs on cow level were inventoried. Taken into account are breeding values, production indicators and Dutch and American performance indicators. Great differences are seen between the Dutch and the American economic KPIs. The Dutch KPIs more focusing on correction factors for a good comparing and the American KPIs more adapted for detecting causes of production changes.
Merit is treated separately here, though it's part of the breeding indexes, other factors (longevity, SCC and fertility) of the breeding indexes are also elaborated in the other categories.
The following KPIs are worked out:

- Breeding indexes
- Merit
- Milk Production indicators
- Dutch performance indicators
    - Net revenue
    - Farm average cow
    - Economic year result
- American performance indicators
    - Milk deviation
    - Expected production
    - Mature equivalent
    - Looser box
    - Cow value

Breeding indexes
Breeding values are developed as helpful tools for breeding the most profitable cow. An example is the Profitable Lifetime Index (PLI). The PLI is introduced more than 10 years ago in the UK, it takes production (merit), longevity, fertility, SCC and locomotion into account. All these factors have a certain weight, creating a profitability index per cow. This PLI is comparable to TPI in the US (Van Raden, 2002), the LPI in Canada (Boettcher, 1999), and NVI in the Netherlands. Every index is a calculation optimized per country, trying to predict the profit breeding value (Pérez-Cabal and Alenda, 2003). For example, a PLI point is worth $6.91.

Merit
Merit is a combination of breeding values for milk, fat and protein production. The formula for Merit is composite in a way that selection on Merit will lead to a more profitable production. Merit is country specific, while it's based on the method of payment by the milk processor. In the Netherlands there is a negative payment on liters milk, so extra liters milk but same kilos fat and protein isn't profitable, see below the formula.

Merit 2012 = -0.03 x Breeding Value (BV) kg milk + 2.2 x BV kg fat + 5.0 x BV kg protein

Because Merit is based on breeding values the dam and sire have great influence on a cow its Merit. After two years when the cow is producing milk the production information is used in the breeding value. Only the first three lactations have influence on the breeding values (CRV, 2013).

Milk production indicators
Milk production is often expressed in liters or in kilogrammes, but both can have variable fat and protein content. Therefore milk production can also be expressed in milk solids or it can be calculated to the energy content of the milk, these are indicators which can be used for comparing

productions. Calculating the energy content of the milk is widely used (especially in studies), and is calculated in fat and protein corrected milk (FPCM) units. The formula is as follows:

FPCM= (0.337 x 0.116 x %fat + 0.06 x % protein) x kg milk (Tabellenboekje, 2007)

Except for days, milk productions can also be expressed for periods. In the Netherlands al lactations are calculated to 305 day productions. In the optimal situation cows calf once a year, so once every 365 days, when you take a dry period of two months into account 305 days for producing milk are left. Other countries often calculate the production to 365 days, for example Scandinavian countries and the US. Calving interval has great influence on production, every cow has its own calving interval, therefore also a lactation production is given. This is the total production for the days the cow was in production.

Often production is also expressed as life production, life production is most dependent on culling age and average milk yield. Because of high rearing cost a high life production is seen as more profitable than a high lactation production. It can be given as a herd average or individual, target overall is creating a high life production.

Dutch performance indicators

In the Netherlands there are many ways of measuring production performance of dairy cows, in contrast to many other countries. The following KPIs are the main adopted KPIs in the Netherlands, striking is the many factors these KPIs gets corrected for.

Net revenue

The net revenue gives the corrected revenue per lactation, therefore lactations can be compared within a firm. Net revenue is calculated on the realized or predicted lactation, but is still corrected on several points. Net revenue is corrected for calving interval, season of calving and age of calving.

Net revenue is an individual trait, however only an average net revenue is given for the herd and per lactation group. Comparing herdmates can be done with the lactation value, lactation value gives the relative performance of a cow in percentage. Because lactation value only gives information of the actual lactation and only within the farm it's not useful for purchase decision (CRV, 2013).

Farm average cow

Another performance production indicator which is used in the Netherlands is the Farm Average Cow. Farm Average Cow gives the average day production of a cow, if the cow is full-grown, calved in February/March and 50 days in lactation. The production of the cow is corrected for fertility status, age, season of calving and lactation stadium. Farm Average Cow is comparable every sampling and a benchmark for the production level of the herd. Farm Average Cow can also be used to detect fluctuations in level of production, causes of this can be feeding, grazing, milk technique, health or weather conditions (CRV, 2013).

Economic year result

Despite this indicators there still was a lack in indicators which give a good view on performance per year like there is in pig business with piglets per sow per year. Therefore CRV introduced in 2002 the Economic Year Result. With Economic Year Result calving interval is taken into account and productions are calculated to year productions. One requirement of the Economic Year Result is that the cow should have calved again, otherwise it's not possible to calculate a calving interval. The Economic Year Result takes production, fertility and sustainability into account (CRV, 2013).

American performance indicators

The following KPIs are a summation of economical KPIs collected from the management system Dairy Comp 305. Less than the Dutch KPIs they're focused on performance and more on detection of causes of changes in production.

Milk deviation

Milk deviation is used to compare test day milk production and is the difference between what the cow produced and what was expected the cow would give. A positive number means the cow gave more than was expected and a negative value means a lower production.

Expected production

The expected production of the cow is the needed production to reach the 305 days production that was calculated the previous test day. Every cow gets an expected production, except the first test day after calving.

Mature equivalent adjusted record

In the Mature Equivalent adjusted record (ME) also the expected production for 305 days is calculated. But now the change in expectation over the monthly test days is expressed. The ME is adjusted for days in milk, age and season of calving and therefore comparable with the Dutch KPI "Farm average cow". There is however one difference, ME is expressed as liters of milk per 305 days and the "Farm average cow" is calculated to a day peak production. Just as the "Farm average cow", ME can be used as a benchmark and then fluctuations in level of production can be detected.

Looser box

Another remarkable indicator in Dairy Comp 305 is "the looser box". This box is set up by two constraints with on the x-axis the days in milk and on the y-axis the liters milk produced. By giving a minimum amount of liters for a certain days in milk a box is plotted (for example not less than 25 kg before 150 days) with a minimum production level. The goal is to have every cow outside of that box (Dairyone.com, 2013b).

Cow value

Cow value is an indicator that can be used for culling decisions. For every cow a value is computed which gives the possible future profit to the dairy farm if the cow is retained vs. being replaced by a heifer. Cow value is expressed in dollars by a Net Present Value (NPV). The calculation for the NPV is based on 3 assumptions, namely the price of milk in the future, the value of the money that must be invested in the animal and the amount of milk the cow is likely to produce in the future. The last assumption can't be made without additional information, information is needed on age, stage of lactation, reproductive status and production level.

The value of a cow which will retain in the herd is calculated, and so is the value of rearing a heifer. The difference between those values is the Cow Value, therefore the Cow Value of a heifer is $0. The cows that have a positive Cow value are economically more valuable than the replacement heifer, therefore the cows with a positive Cow Value should stay in the herd. For cows with a negative Cow Value culling could be an option (Dairyone.com, 2013a).

Based on the Cow Value, considerations can be made to breed a cow, or when sick to treat cow (Eicker, 2003). A cow with a negative Cow Value won't be bred or treated. A cow with a Cow Value of $50 and a displaced abomasum can be more profitable culled than treated.

3. Material and methods

In the literature study an overview is made of the existing KPIs in dairy farming. The effect of the available KPIs on milk revenues will be analyzed. Also the effect of some new KPIs are investigated. Two analyses will be done, the first analysis will focus on the effect of health KPIs on milk revenue in the first 100 days of lactation. The goal of the analysis is to determine the health KPIs that have an effect on milk revenue. The second analysis will focus on the effect of KPIs on milk revenue in the whole lactation. The goal of this analysis is to determine which KPIs have the largest effect on milk revenue.

Available data
Data was available from two American dairy farms. The first one is located in Wisconsin, and has a herd size of 793 dairy cows in 2013. The second farm is also located in Wisconsin, and has a herd size of 267 dairy cows in 2013. The second farm is a comparatively new farm, only three years ago the farmer started. Both farms are using the decision supporting program CowManager (since June 2012 and December 2012, respectively), and from both farms SensOor data is available. The SensOor is attached in the eartag of the cow, and serves as a heat and health detecting system. The SensOor is measuring cow related factors (activity, rumination minutes, eating minutes, inactivity and temperature), and is collected continuously. Data used for the current analyses are rumination minutes, eating minutes and sick alerts. Activity and temperature are not included in the analyses because activity can only be used for heat detection and temperature is measured in the ears and is not an absolute value. Moreover, temperature varies between cows what makes it hard to compare.
The total number of minutes ruminating and eating per hour are available from the SensOor.
From the first farm SensOor data was available from 5 June 2012 till 2 December 2013, and from the second farm SensOor data was available from 2 December 2012 till 19 January 2014. From both farms also data out of Dairy Comp 305 was available. Dairy Comp 305 is an American dairy management system and contains management information on breeding, production, fertility and health of individual cows.

3.1 Data for first analysis

For the first analysis only the first 100 days of the lactation are taken into account, which resulted in complete information on 916 cows. The first of these cows calved at 3 June 2012, the last lactation started 24 September 2013 and reached the 100 days in lactation on 2 January 2014.

Out of the management program Dairy Comp 305 for each cow until 100 days in lactation the following cow information variables were selected:

- Parity
- Number of mastitis treatments
- Number of metritis treatments
- All somatic cell count measurements

Out of the management program CowManager for each cow until 100 days in lactation the following cow information variables were selected:

- Average rumination minutes per day
- Average eating minutes per day
- Hours sick

In addition, other cow information variables for the first 100 days in lactation were calculated based on the available data, which are:

- Total hours sick

- Total hours sick in first 30 days of lactation
- Total hours sick pre-partum
- Pre- / post-partum rumination
- Pre- / post-partum eating
- Rumination/eating ratio

For all 916 cows the total milk production (in pounds) until 100 days in lactation was selected out of the management program Dairy Comp 305. Subsequently, the milk production was multiplied with $17 per cwt (Merlo, 2013) to determine the milk revenues. The average cow in the database had a milk revenue of $1,605, and the maximum milk revenue was $2,919.

Each of the mentioned cow information variables are summarized in a KPI, and these will be discussed in more detail below. Distinction have been made between KPIs that are parted up in classes and that have an continuous outcome.

The parity of the cows in dataset 1 was on average 2.2. In Table 3.1 is shown that the amount of heifers and twice calved cows is very high. After the second lactation the amount of cows per parity declines fast, it almost halves every lactation. Therefore is chosen to categorize parity into three categories, first-calf heifers, second-calf cows and older cows.

Table 3.1 Frequency distribution of class KPIs in dataset 1

Parameter	Class	Frequency	Percentage
Parity	1	313	34.2
	2	345	37.7
	≥3	258	28.1
Number of mastitis treatments	0	822	89.7
	1	94	10.3
Number of metritis treatments	0	875	95.5
	1	39	4.3
	2	2	0.2
Number of times increased SCC (>200,000 cells/ml)	0	664	72.5
	1	161	17.6
	2	48	5.3
	3	42	4.6

In total, 94 out the 916 cows were treated once in the first 100 days for mastitis (see Table 3.1). There were no cows treated more than once for mastitis. In the same period 41 out of 916 cows were treated for metritis, 2 cows were even treated twice.

Somatic cell count (SCC) is measured once a month by a milk test. During the first 100 days in lactation there are about three test days. In total, three KPIs for somatic cell count are defined. First, the average over the first three test days. Secondly, the highest value of the three test days and finally, the number of times increased SCC (above 200,000 cells/ml (Fetherston, 2001)). For the statistical analysis also the log of the SCC is calculated.

In average SCC the minimum and the maximum were 9,000 and respectively 5,373,000 cells/ml. On average the cows had an SCC of 183,000 cells/ml. SCC can be measured till 9,999,000 cells/ml, this is also the maximum in peak SCC, minimum of the peak in SCC is 12,000 cells/ml, the 5% boundaries are given in Table 3.3. The number of times increased SCC varied between 0 and 3 times (Table 3.1).

The minimum rumination time of a cow was 332 minutes per day, and the maximum was 822 minutes per day. On average a cow ruminated 596 minutes per day during the first 100 days of a lactation. The minimum eating time was 19 minutes per day and the maximum eating time was 564 minutes per day. On average spent a cow 283 minutes on eating per day in the first 100 days of lactation. Rumination and eating minutes are also parted up in four classes, these classes are based on quartiles (Table 3.2).

Table 3.2 Frequency distribution of the class KPIs eating minutes, rumination minutes and hours sick in dataset 1

Parameter	Class	Range	Frequency
Rumination minutes	1	332 - 543	231
	2	543 - 593	230
	3	593 - 649	228
	4	>649	227
Eating minutes	1	19 - 216	230
	2	216 - 282	232
	3	282 - 349	229
	4	>349	225
Hours sick	1	0 - 1	256
	2	1 - 13	207
	3	13 - 31	227
	4	>31	226

Besides rumination and eating also sick alerts were taken into account. Sick alerts are based on deviations in eating, rumination, inactivity and temperature compared to the previous 7 days. Normally these sick alerts are used as an action tool, by showing a sick cow on the dashboard. Now it's computed to a KPI, by summing up all hours sick, so the effect on performance can be analyzed. The KPIs computed are "Total hours sick " and "Total hours sick in the first 30 days". These KPIs are a summation of the hours sick post-partum till 100 days and 30 days, respectively. For "Total hours sick" a class variable is made, these classes are parted up by quartiles (Table 3.2).
The maximum total hours sick in the first 100 days was 282 hours sick. The maximum hours sick in the first 30 days is 206 hours. Averages for both KPIs are shown in Table 3.3.

Table 3.3 Descriptive statistics for 8 continuous KPIs in dataset 1

Parameter	Average	5% - 95%	Unit
Average SCC	183	14 - 845	SCC point
Peak SCC	376	18 - 1,734	SCC point
Total hours sick	22	0 - 75	Hours
Hours sick first 30 days	12	0 - 51	Hours
Hours sick pre-partum	3	0 - 21	Hours
Pre/post-partum rumination	0.91	0.11 - 1.13	Ratio
Pre/post-partum eating	1.22	0.59 - 2.80	Ratio
Rumination/eating ratio	2.51	1.16 - 5.06	Ratio

Because not only factors within these 100 days have influence on performance a few indicators pre-partum are taken into account. First is "Hours sick pre-partum" defined, which is the hours sick of the cow in the dry period from 14 days before calving till calving. The amount of hours sick pre-partum vary from 0 to 108 hours sick.
Because eating/rumination and health are closely related also a KPI is made on change in rumination and eating pre- and post-partum. Officially the transition period is marked as three weeks pre-partum and three weeks post-partum (Grummer et al., 2010). Therefore these KPIs are computed as the average rumination time three weeks pre-partum divided by the three weeks post-partum average. The cow which increased the most in rumination minutes post-partum had a ratio for "pre/post rumination" of 0.07. The cow which decreased the most in rumination minutes had a ratio of 1.96. The same calculation was performed for eating. The minimum pre-/post-partum eating ratio is 0.47 and the maximum ratio is 4.40. For both KPIs the averages are given in Table 3.3.
Also a KPI on efficiency in eating is defined. This KPI is called rumination/eating ratio which is calculated by dividing the rumination minutes by the eating minutes. The minimum rumination/eating ratio was 0.74 and the maximum was 34.35. The average rumination/eating ratio was 2.51 (Table 3.3).

3.2 Data for second analysis

For the second analysis, lactations of at least 280 days are taken into account, which resulted in information on 458 cows. These cows calved between 07-06-2012 and 13-05-2013. Data was available of the same two farms as in the first analysis.

Out of the management program Dairy Comp 305 for each cow the following cow-information variables were selected:

- Parity
- Fat percentage measurements
- Protein percentage measurements
- Peak production
- Number of days in lactation at peak production
- Somatic cell count measurements
- Service rate
- Number of days open before pregnancy
- Ease of calving
- Number of metritis treatments
- Number of mastitis treatments

Out of CowManager the following variables were selected:
- Average rumination minutes per day
- Average eating minutes per day
- Hours sick

Based on available data the following variable is calculated:
- Rumination/eating ratio

As performance indicator milk revenue was taken into the analysis. For milk revenue the same estimated milk price is taken as in the first analysis, $17 per cwt. The production used now is taken over the whole lactation period, till 305 days. Production after 305 days was not taken into account. For the cows which had a lactation a little shorter than 305 days the predicted 305 day production was taken. Average milk revenue was $4,431 and the maximum was $7,024.

Each of the mentioned cow information variables are summarized in a KPI, and these will be discussed in more detail below.

In table 3.4 the continuous KPIs are given, including fat and protein percentage. These percentages are averages over 305 lactation days. The cows realized an average fat percentage of 3.54% and an average protein percentage of 2.89%. The minimum and maximum for fat percentage were respectively 2.2% and 5%. The produced protein percentage varied between 2.4% and 3.5%. Peak production varies between 58 and 190 lbs. The average day of peak production was at day 91 of the lactation (Table 3.4).

Table 3.4 Descriptive statistics of 10 continuous KPIs in dataset 2

Parameter	Average	5% - 95%	Unit
Fat percentage	3.54	2.6 - 4.5	%
Protein percentage	2.89	2.5 - 3.3	%
Peak production	107	74 - 154	Lbs
Peak day	91	28 - 273	Day
Average SCC	127	18 - 488	SCC point
Average log SCC	1.84	1.26 - 2.69	Log point
Peak SCC	556	37 - 2,198	SCC point
Peak log SCC	2.33	1.57 - 3.34	Log point
Days open	192	65 - 423	Day
Rumination/eating ratio	2.92	2.21- 4.31	Ratio

Somatic cell count is gathered in two ways, as an average over 305 days and as the peak in SCC (Table 3.4). Parity is parted up in three classes, shown in Table 3.5. In the third class are cows of parity 3 till 7. Within the second database the service rate varied between 0 and 12 times. The higher number of inseminations decreased in amount, therefore service rate is parted up in classes. Six services and more are together in class 6. Another fertility KPI which is defined is days open. Days open are the amount of days a cow is not pregnant during the lactation. On average the cows in this database had 192 open days. Every time a cow calves, the ease of calving is scored. The ease is scored on a scale of 1 to 5 (1=easy and 5 is very difficult). Also the amount of metritis treatments and mastitis treatments were defined, frequencies per incidence are given in Table 3.5.

Table 3.5 Frequency distribution of 5 class KPIs in dataset 2

Parameter	Class	Frequency	Percentage
Parity	1	178	38.9
	2	166	36.2
	≥3	114	24.9
Service rate	0	20	4.4
	1	109	23.8
	2	100	21.8
	3	66	14.4
	4	57	12.4
	5	47	10.3
	≥6	59	12.9
Calving ease (easy to difficult)	1	417	91.0
	2	6	1.3
	3	26	5.7
	4	3	0.7
	5	6	1.3
Number of mastitis treatments	0	371	81.0
	1	49	10.7
	≥2	38	8.3
Number of metritis treatments	0	423	92.3
	1	28	6.0
	≥2	8	1.7

Out of CowManager rumination and eating minutes are derived. On average the cows ruminated 593 minutes and ate 295 minutes per day. These KPIs are parted up per quartile, the boundaries are given in Table 3.6. Maximum average rumination time was 763 minutes per day, and minimum average rumination time was 369 minutes per day. The maximum average eating time was 503 minutes per day, and the minimum eating time was 36 minutes per day (Table 3.6).

Table 3.6 Frequency distribution for the class KPIs rumination, eating and hours sick in dataset 2

Parameter	Class	Range	Frequency
Rumination minutes	1	369 - 549	113
	2	549 - 585	114
	3	585 - 637	116
	4	>637	115
Eating minutes	1	36 - 238	114
	2	238 - 296	115
	3	296 - 354	114
	4	>354	115
Hours sick	1	0 - 11	115
	2	11 - 29	117
	3	29 - 56	114
	4	>56	112

Maximum hours sick in the second database was 227 hours. These hours sick are over the whole lactation period, till 305 days, on average the cows were 39 hours sick. Just as rumination and eating are hours sick parted up per quartile.
As new KPI the ratio rumination/eating was defined. This ratio had a minimum of 0.90 and a maximum of 18.35. On average the cows had a rumination/eating ratio of 2.92 (Table 3.4).

3.3 Statistical analyses

Data preparation and analysis was performed in SAS version 9.3 (SAS Institute Inc., Cary, NC). Data preparation included the parting up in classes and determination of the boundaries (quartiles). Statistical analyses were performed to determine which KPIs effect milk revenues using a generalized linear model in SAS (PROC GLM). In the statistical analysis milk revenue was defined as the dependent variables and all defined KPIs are defined as independent variables.
All variables were analyzed using a backward stepwise procedure. Only variables at $P \leq 0.05$ in the Wald test were retained in the model. Parity, calving season and farm were forced into the model. In addition, biological plausible interaction terms were investigated, and included hours sick with farm, parity and pre-/post-partum rumination and eating, farm with SCC and parity and average rumination with average eating. Before the tests were done KPIs were tested on underlying covariance (PROC CORR)". Variables with a correlation greater than 0.8 were analyzed separately, the variables which caused the highest R-square were chosen above the other "related" variable.

4. Results

4.1 Results first analysis

In Table 4.1 the KPIs are presented which made it through the stepwise backward selection for the analysis of milk revenue in the first 100 days of lactation. None of the interactions made a significant difference and were not included in the final model. Together the variables were good for a R-square of 0.677 in the first analysis. So 67.7% of the variance on milk revenue can be explained with these KPIs.

Table 4.1 Significant independent variables of the generalized linear model for milk revenue in the first 100 days of lactation

Parameter	DF	F Value	P-value
Peak SCC	1	8.61	0.0030
Average rumination	1	30.04	0.0001
Average eating	1	10.3	0.0010
Pre/post-partum rumination	1	5.15	0.0230
Hours sick <30 days	1	43.09	0.0001
Sick pre-partum	1	9.45	0.0020
Metritis	2	5.13	0.0060
Parity	2	491.35	0.0001
Farm	1	455.79	0.0001
Season	3	10.43	0.0001
Year	1	9.79	0.0020

The 11 variables (Table 4.1) were the outcome of backward selection and are a mix of KPIs coming from Dairy Comp 305, CowManager and KPIs calculated out of the other variables. Largest influence on milk revenue had the variables parity and farm, with a F-value over 400.

In Table 4.2 an overview is given of all variables in the final model and their estimates for milk revenue. Every point higher in SCC resulted in a $0.02 lower milk revenue per cow. Average rumination gives a difference in milk revenue of $0.59 per extra rumination minute. This is almost twice as much as every extra eating minute. An extra eating minute resulted in a $0.30 higher milk revenue per cow. The ratio pre-partum rumination divided by post-partum rumination resulted in $0.55 higher milk revenue for cows which ruminates more before calving.

Table 4.2 Coefficient estimates of the generalized linear model for milk revenue in the first 100 days of lactation

Parameter	Estimate	Standard Error	t Value	P-value
Intercept	1,496.76	164.92	9.08	0.0001
Peak SCC	-0.02	0.01	-2.93	0.0034
Average Ruminating	0.59	0.11	5.48	0.0001
Average eating	0.30	0.09	3.21	0.0014
Pre-/post-partum ruminating	-0.55	0.24	-2.27	0.0234
Hours sick <30 days	-2.07	0.32	-6.56	0.0001
Sick pre-partum	-2.36	0.77	-3.07	0.0022
Metritis 0	259.10	144.98	1.79	0.0743
Metritis 1	166.97	148.26	1.13	0.2604
Metritis 2	Ref.	0.00	0.00	0.0000
Parity 1	-532.55	19.18	-27.77	0.0001
Parity 2	-102.62	19.22	-5.34	0.0001
Parity ≥3	Ref.	-	-	-
Farm 1	-415.33	19.45	-21.35	0.0001
Farm 2	Ref.	-	-	-
Season Jan - Mar	43.77	36.35	1.20	0.2288
Season Apr - Jun	57.75	34.93	1.65	0.0986
Season Jul - Sep	-39.77	32.21	-1.23	0.2173
Season Oct - Dec	Ref.	-	-	-
Year 2012	91.20	29.15	3.13	0.0018
Year 2013	Ref.	-	-	-

Sickness pre-partum costs more than sickness in the first 30 days of the lactation. Every hour sick pre-partum per cow reduces the revenue with $2.36 and post-partum with $2.07. Despite off that sick pre-partum reduces the milk revenue more, does sickness in the start of the lactation have a higher predictive value for the final milk revenue (Table 1). To express the effect of hours sick on milk revenue a “standard cow” is created. This cow has for every continuous variable the average value, and for every class variable the most common value. This resulted in a cow which produces in 100 days a milk revenue of $1,724. In Figure 4.1 the effect of Hours sick in the first 30 days and sick pre-partum on milk revenue is presented. Sick pre-partum has a slightly larger effect than sick in the first 30 days.

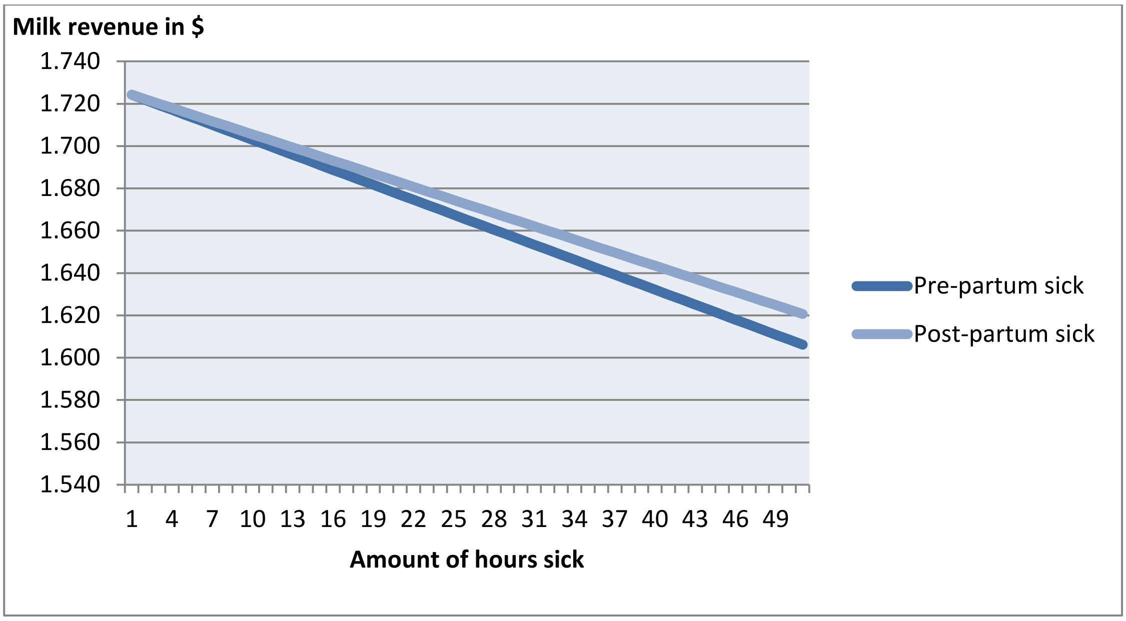

Figure 4.1 Effect of pre- and post-partum hours sick on milk revenue in the first 100 days of lactation

Milk revenue is decreasing with increasing number of metritis treatments (Figure 4.2). Cows which weren't treated for metritis realized a milk revenue of $1,874, while cows which were treated ones for metritis had a milk revenue of $1,776. Metritis was treated at max twice at cows in the first 100 days. These cows realized a milk revenue of $1,615.

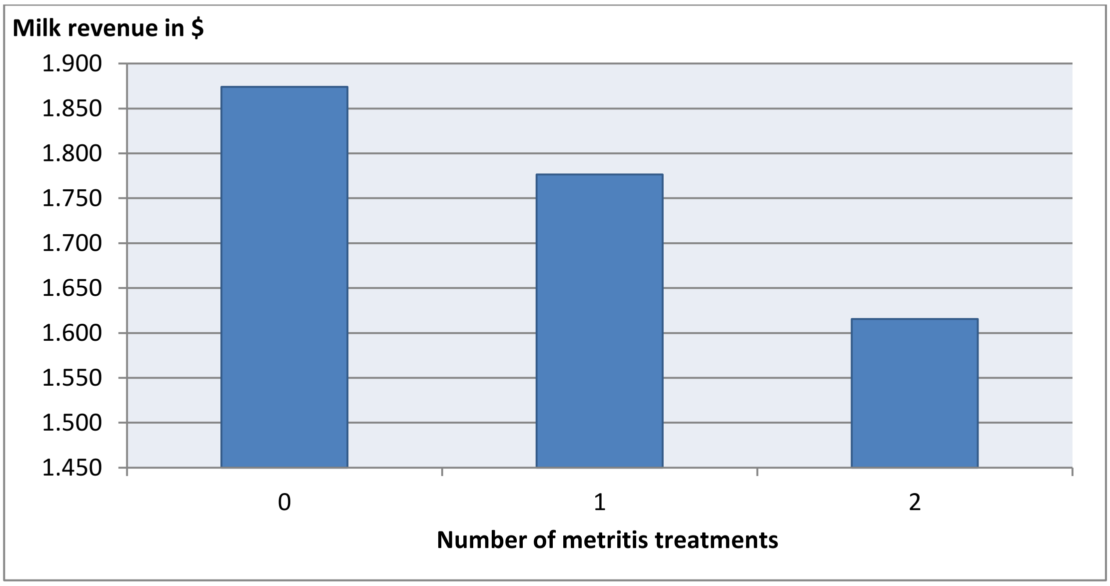

Figure 4.2 Effect of number of metritis treatments on milk revenue in the first 100 days of lactation

In Figure 4.3 the differences in milk revenue per parity is presented. Milk revenue is increasing with increasing parity (Figure 4.3). The shifting to a higher parity group generates a higher milk revenue, the first shift leads to an increase of $430 from $1,314 to $1,744. A shift from parity two to three leads to an extra increase of about $100 to $1,846. All of the differences in milk revenues between the parity groups were significant.

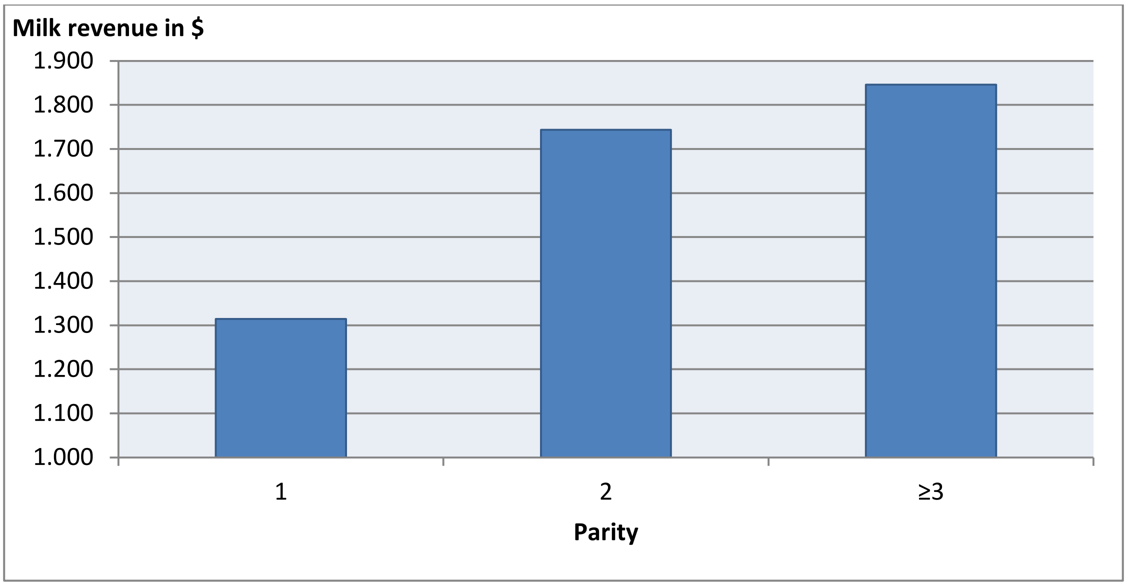

Figure 4.3 Effect of parity on milk revenue in the first 100 days of lactation

The next three variables are not cow related, but management related. Out of Table 4.2 it seems that one of the farms had a considerably higher average milk production than the other. Farm 2 had a $415 higher average revenue per cow. The season in which a cow calved also had influence on the milk revenue (Figure 4.4).

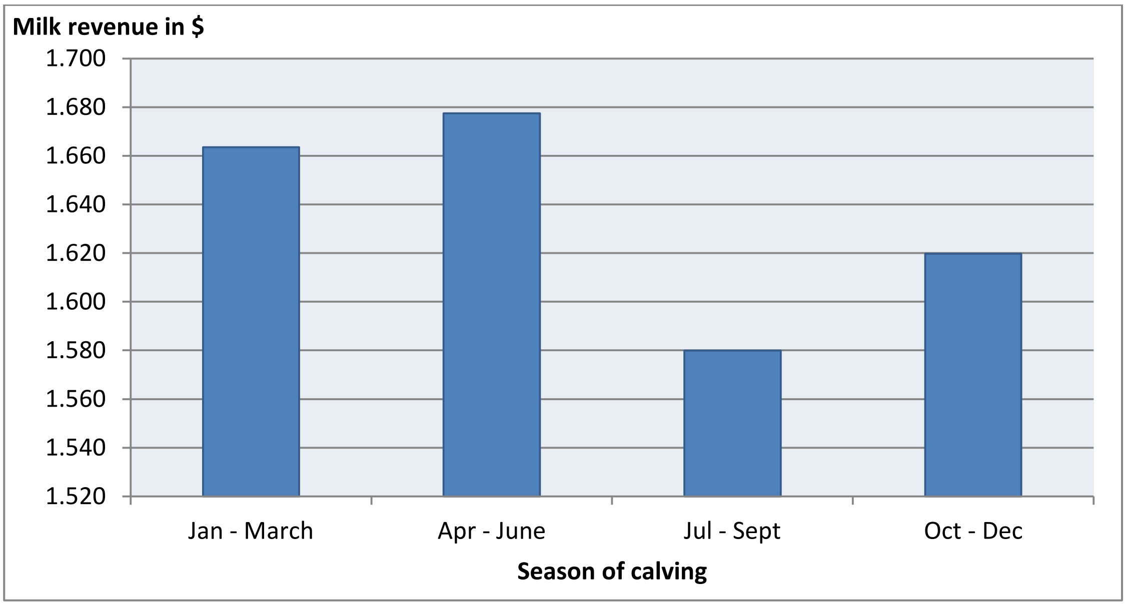

Figure 4.4 Effect of calving season on milk revenue in the first 100 days of lactation

In this study, the season of calving influenced milk revenue (Figure 4.4). Especially the cows which calved in the third quarter had a lower milk revenue, only $1,580. This is low enough to make it significant against to the first two quartiles, but not against to the fourth quartile where the cows had an average milk revenue of $1,620. The cows that calved in the first two quartiles had an average milk revenue of respectively $1,664 and $1,674. Against the fourth quartile the differences was also not large enough to make it significant.

Also year of calving was significant in the final model (Table 4.2). Cows which calved in 2012 realized a milk revenue of $1,680, almost $100 higher than cows calved in 2013.

4.2 Results second analysis

As mentioned in material and methods all available KPIs were taken into account in this analysis, including fertility KPIs. After backward selection 9 KPIs remained in the model and gave an R-square of 0,642. This means that 64.2% of the variance on milk revenue can be explained with this model. In Table 4.3 the KPIs are given which made it through the backward selection. Category rumination is forced into the model over rumination as a continuous variable.

Table 4.3 Significant independent variables of the generalized linear model for milk revenue over the whole lactation

Source	DF	F Value	P-value
Farm	1	211.67	0.0001
Fat percentage	1	6.26	0.0127
Protein percentage	1	60.82	0.0001
Service rate	6	4.95	0.0001
Metritis	2	3.90	0.0210
Cat. Rumination	3	4.08	0.0071
Cat. Eating	3	7.36	0.0001
Cat. Sick	3	3.04	0.0289
Parity	2	150.49	0.0001

Three of the variables had an obvious larger effect on milk revenue than the other variables, see the F-value in Table 4.3. This effect is also visible in table 4.4 where those three have by the largest effect on milk revenue. Striking are the variables category rumination, category eating and category sick, in the first analysis these variables were present as a continuous variable.

In Table 4.4 the final variables are shown, with their estimates. The intercept of the outcome of this model is $8,957. Most variables have a negative effect on milk revenue. Just as farm, difference between the two farms is $1,001, cows on the first farm will realize a much lower milk revenue.

Table 4.4 Coefficient estimates of the generalized linear model for milk revenue over the whole lactation

Parameter		Estimate	Standard Error	t Value	P-value
Intercept		8,957.03	391.62	22.87	0.0001
Farm	1	-1,000.60	68.78	-14.55	0.0001
Farm	2	Ref.	-	-	-
Fat percentage		-125.04	49.96	-2.50	0.0127
Protein percentage		-965.08	123.74	-7.80	0.0001
Service rate	0	-341.49	113.44	-3.01	0.0028
Service rate	1	-321.98	71.69	-4.49	0.0001
Service rate	2	-186.10	73.10	-2.55	0.0112
Service rate	3	-262.64	79.41	-3.31	0.0010
Service rate	4	-112.96	81.26	-1.39	0.1652
Service rate	5	-76.33	85.02	-0.90	0.3698
Service rate	≥6	Ref.	-	-	-
Metritis	0	424.35	168.31	2.52	0.0120
Metritis	1	310.38	186.85	1.66	0.0974
Metritis	2	Ref.	-	-	-
Cat. Rumination	1	-222.24	64.27	-3.46	0.0006
Cat. Rumination	2	-112.53	62.64	-1.80	0.0731
Cat. Rumination	3	-84.76	59.02	-1.44	0.1517
Cat. Rumination	4	Ref.	-	-	-
Cat. Eating	1	-311.58	69.57	-4.48	0.0001
Cat. Eating	2	-243.35	63.46	-3.83	0.0001
Cat. Eating	3	-152.32	59.03	-2.58	0.0102
Cat. Eating	4	Ref.	-	-	-
Cat. Sick	1	153.86	59.82	2.57	0.0104
Cat. Sick	2	112.68	59.24	1.90	0.0578
Cat. Sick	3	20.73	59.36	0.35	0.7272
Cat. Sick	4	Ref.	-	-	-
Parity	1	-933.64	57.19	-16.33	0.0001
Parity	2	-310.26	58.89	-5.27	0.0001
Parity	≥3	Ref.	-	-	-

Fat percentage also had a significant effect, every extra percentage increase in milk fat leads to a $125 lower milk revenue. This can have quite some effect, as is shown in material and methods fat percentage varies between 2.2% and 5%. Protein percentage even had a larger effect, every percentage increase in milk protein causes a lower milk revenue of $965 (Table 4.4).

Service rate is one of the variables which is parted up as a class variable. In Figure 4.5 the effect is visible of the service rate on milk revenue, despite one outlier an increasing trend is observed.

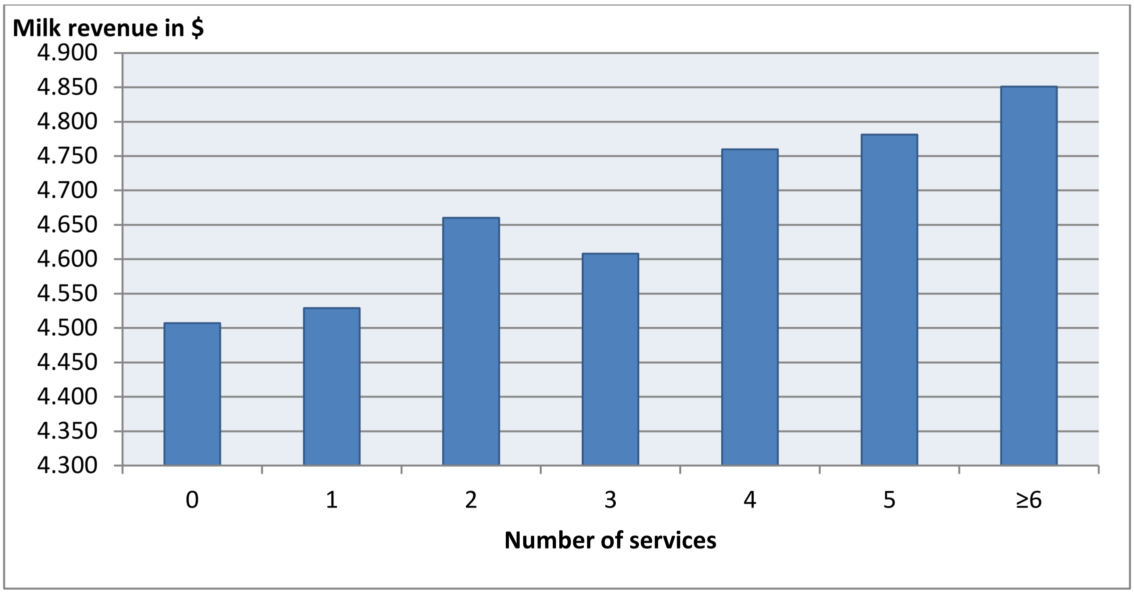

Figure 4.5 Effect of service rate on milk revenue over the whole lactation

The cows that weren't bred realized a milk revenue of $4,510, per insemination this is slowly increasing to a milk revenue of $4,851 for cows which were bred 6 times and more. Cows which were inseminated twice was an outlier, with a higher milk revenue then cows which were inseminated three times.
For metritis same effect is visible as in the first analysis, but now it has almost doubled. Was the difference between cows with two treatments and no treatments in the first analysis $259, in the second analysis it was $424. Difference between two treatments and one treatment was in the first analysis $167 and in the second analysis $310. Only the first mentioned difference was significant.
Cows which didn't need a treatment on metritis realized a milk revenue of $4,839 against a milk revenue of $4,415 for cows with two treatments on metritis. In the following figure the effect of rumination, eating and sick on milk revenue is given.

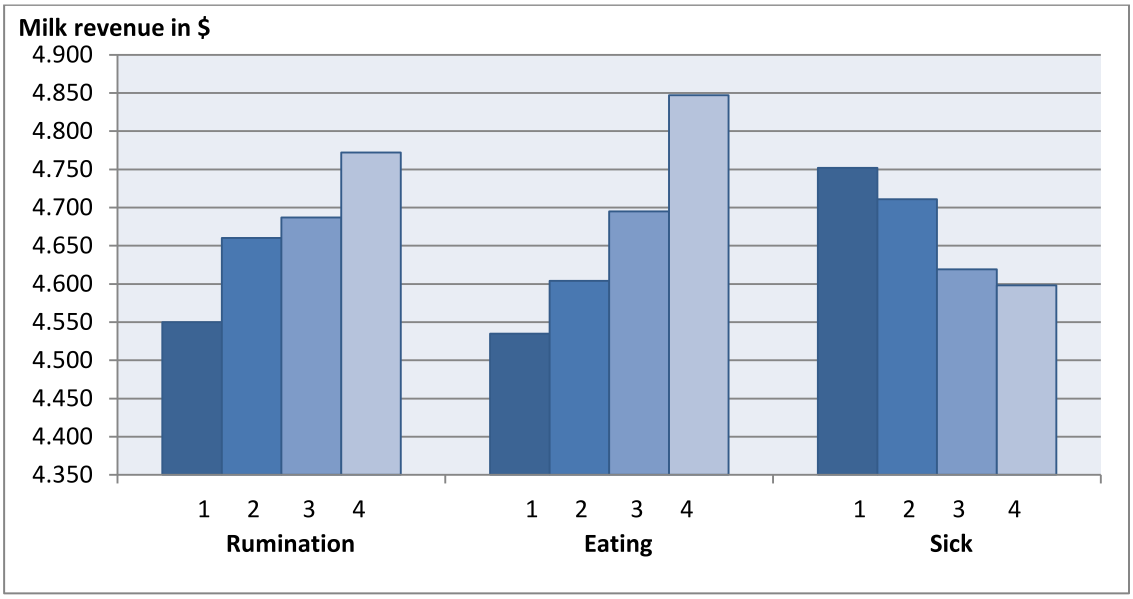

Figure 4.6 Effect of class variables rumination, eating and sick on milk revenue over the whole lactation. (Ranges of class variables are Rumination, 1 = ≤ 549, 2 = 549 – 585, 3 = 585 – 637, 4= ≥ 637) (Eating, 1 = ≤ 238, 2 = 238 – 296, 3 = 296 –354, 4 = ≥ 354) (Sick, 1 = ≤ 11, 2 = 11 – 29, 3 = 29 – 56, 4 = ≥ 56)

In figure 4.6 two trends are visible, increasing in milk revenue per class for rumination and eating, and decreasing per class for sick. The cows in the first class for rumination ruminated less than 549 minutes and were good for a milk revenue of $4,550. Cows in one class higher had a milk revenue of $4,660. In class 3 and 4, the cows had a milk revenue of respectively $4,687 and $4,772. The differences in milk revenue were large between the rumination classes, but only the differences between classes 1 and 3 and between classes 1 and 4 were significant . For eating even a larger increase in milk revenue is shown than for rumination (see Figure 4.6). The cows in the lowest class had milk revenue of $4,535 and increases to $4,847 in the highest class. Class 4 is significant different with all classes, also class 3 is significant different from class 1. Just as the two variables before the classes for sick are parted up in quartiles. The exact boundaries of the classes are given in material and methods and the caption of figure 4.6. Milk revenue decreases slowly between these classes, from $4,752 in the first class to $4,711 in the second class. Classes 3 and 4 continued the decrease with a milk revenue of $4,619 in the 3rd class and $4,598 in the 4th class. Significant differences were found between classes 1 with 3 and 1 with 4.

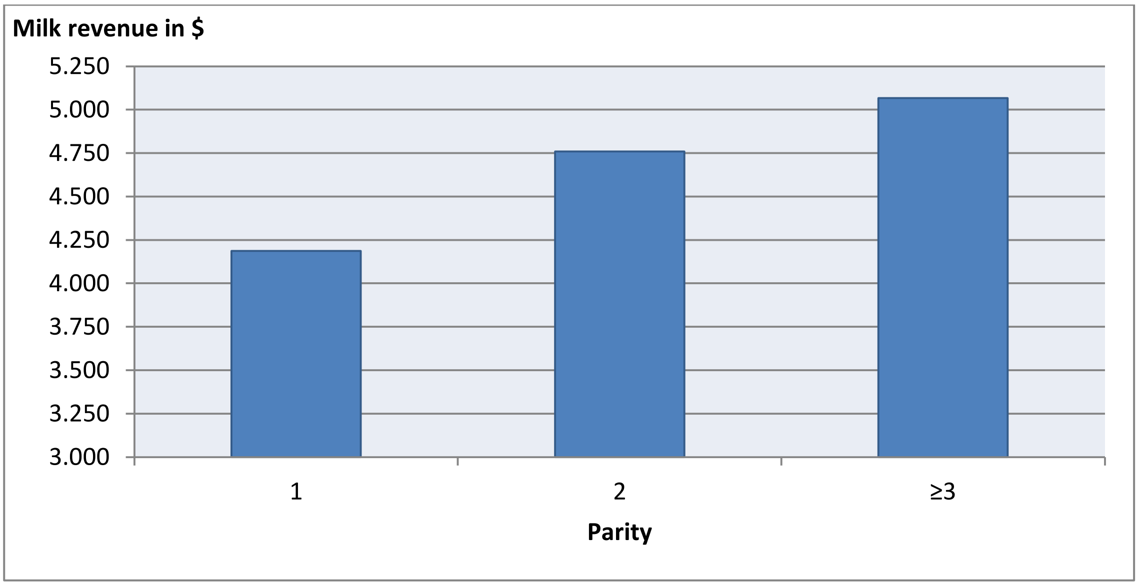

Figure 4.7 Effect in milk revenue over the whole lactation by parity

In Figure 4.7 the effect of parity on milk revenue is given. All effect between the classes are strongly significant. Cows in the first class provides a milk revenue of $4,186 which is even $623 lower than the cows in the 2nd lactation class. In the 3rd class the milk revenue rises to $5,119 for the cows which calved three times and more.

5. Discussion

In this chapter the results of the study on KPIs with the largest economic effect is discussed, as well as factors which might affect them. Comparable studies which take multiple KPIs into account weren't found. However, the effect of single KPIs on the economic effects is performed (e.g. Sørensen, 2003; Groenendaal et al.). Due to a lack of suitable performance indicators in the US dairy sector, a performance indicator is created in this study. This performance indicator is called milk revenue and is based on milk production and the milk price. Many performance indicators in the Netherlands are based on milk production as well (e.g. net revenue or farm average cow), but they also take fertility into account. In the current study, fertility isn't directly taken into account in milk revenue. With a performance indicator that takes fertility more into account probably more fertility KPIs would last after the stepwise backward selection.

Besides milk production there are more kinds of revenues (such as livestock sales), which aren't taken into account with milk revenue but are influenced by some KPIs. Milk revenue also doesn't take costs into account. In several studies costs were taken into account (e.g. Halasa et al., 2007; Inchaisri et al., 2010), and therefore comparing literature with current results is difficult.

The literature study focused on four categories to distinguish KPIs: fertility, health, feeding and economy. These four fields were assumed as the most important and determining fields. A fifth category, production, was combined in economy. This structured approach did exclude a few KPIs (for example milking speed and KPIs for young stock), but also led to a better overview and a more complete research per category.

An overview is made on KPIs which are currently available to dairy farmers. In the end not all KPIs out of the literature study could be taken into account in the final data analyses. Despite of a delimitation in the literature study for KPIs which only measure performance on cow level, a few herd level KPIs were taken into account in the literature study. Clearly this delimitation wasn't clear enough. For example, heat rate and conception rate are measured on cow level, but are shown at herd level and can't be translated to cow level. These KPIs couldn't be taken into account within the analysis. Underlying KPIs as service rate and days open were taken into account. Other KPIs weren't available, like animal daily dose, or weren't realized yet, like longevity.

Many health disorders were described in the literature study, seven in total. Four of these health disorders were available in Dairy Comp 305. However, only two of these health disorders were tracked in the right way by both farms, metritis and mastitis. All other health disorders were therefore left out the analyses. In the literature it was found that mastitis was one of the most common health disorders and therefore one of the most costly disorders (Hogeveen et al., 2011). Nevertheless, in both analyses mastitis wasn't taken into the last variables with the largest economic influence. Striking was the low amount of cows which were treated for mastitis. In the first analysis only 94 cows (a little more than 10%) were treated once for mastitis, and no multiple treatments were recorded.

In America bulk tank SCC should be lower than 750,000 cells/ml, and this may be the reason that only cows with clinical mastitis were treated. Another cause can be that only high productive cows got an increased SCC, and therefore production losses weren't noticed against the other cows. This can also explain the relative low economic effect of peak SCC. Every point higher in peak SCC reduces the revenue with $0.02, in literature a much higher effect was found. According to Steeneveld et al. (2007) a subclinical mastitis case costs on average $149.

Many studies investigated the effect of an extended calving interval. On beforehand great influence of calving interval on milk revenue was expected. However, in most of the cases cows haven't finished the lactation yet, so no calving interval was known for these cows. An alternative KPI is open days. Open days is quite similar to calving interval, because the duration of a pregnancy is quite constant. Open days had no significant economic effect. An extra open day doesn't reduce the milk revenue, because it increases the lactation duration. It does reduce the average day production and therefore it increases the relative feeding costs. But average day production and feeding costs weren't taken into account in this study.

According to the results does the milk revenue rise with every time a cow gets served. This suggests that the service rate is not an independent variable but dependent. Not only does a high yielding cow get an "extra chance", also a deferred pregnancy leads to a higher milk production. The same reaction was described in the literature by González-Recio et al. (2004). Cows that needed more inseminations produced more milk per lactation, but had a higher culling risk and a lower lifetime day production, which reduced profit.
Bartlett et al. (1986) found that metritis costs on average $106 per cow per lactation. The same trend was found in results of this study. Reduced revenue by metritis was on average $90 for both analyses. No treatment costs were taken into account, when treatments costs are taken into account it makes it comparable to Bartlett's outcomes. However, multiple treatments for metritis reduced revenue even two and four times more than a single treatment in analysis 1 and analysis 2, respectively. Out of these results it can be concluded that metritis affects the whole lactation production and not just the peak in production.

For both analyses data was available of two American dairy farms. On beforehand data of more farms was expected, but due to the newness of the SensOor just a few farms were equipped for a longer time with the SensOor. Another criteria was the use of management program Dairy Comp 305, this last criteria led to two farms with available data. Nevertheless there was data available of sufficient cows, according to Field (2009) 10 to 15 records per predictor variable is enough. The first analysis, which took 11 predictor variables into account, had data available of 916 cows. The second analysis took 9 variables into account and had with complete data of 458 cows enough records.
Only cows with complete information were taken into the analyses, though in the second analysis an exception is made. Instead of only cows with more than 305 days in lactation, also cows from 280 days in lactation were selected. Expected is a low influence on KPIs in the last days, however for milk revenue the predicted 305 days milk production is taken of these cows. This lower criteria resulted in 60 more cows in the analysis.

In the first analysis a few variables were taken into account which aren't real KPIs, but do have a high predictive power. Influence of farm is high in this model, this won't change with data available of more farms. For a farm itself this variable is not very useful. Another variable in the model with much influence is parity. Probably not directly parity will influence revenue, but age certainly does. Older cows have almost a $900 higher milk revenue over 305 days than heifers. On parity indirectly can be managed, for example by lowering culling rate. Season of calving and year of calving are also difficult variables to manage on. Year of calving is influenced by many other factors, like roughage quality and milk price. Therefore this variable is also not very useful to the farmer. Season of calving can be managed on, however, due to a calving interval larger than a year this will shift every year. The third season is the least profitable season to let cows calve in, this season can tried to be avoided.
Milk price is paid in the US in total a different way than is done in Europe. Instead of a price paid per component and amount, the milk is classified and paid per litre. Especially the American Holsteins are bred for this litre based paying system. Fat- and protein content has a negative influence on milk production. The second analysis shows a negative economic influence of fat of $125 per percent and even $965 per percent protein. This concludes that breeding on liters is paying off in the American pricing system.

In the first analysis an extra rumination minute gives almost twice as much revenue as an extra eating minute. In the second analysis average rumination and average eating were parted up in four equal sized classes. Difference between the lowest and highest group were for eating $312 which is one and a half time higher than the difference between the lowest and highest class in ruminating. When maximizing profit/revenue it's interesting to focus on rumination in the start of the lactation, while over the whole lactation it pays off to manage on eating minutes.

Sick pre-partum and sick post-partum were distinguished in the first analysis. Sick pre-partum had a slightly larger influence on milk revenue than sick post-partum, however, sick post-partum had a higher predictive value in the analysis. In the second analysis sick was parted up in four equal classes. Here a difference of $154 was found between the sickest and the healthiest cows. These outcomes confirmed the earlier findings.

A special KPI is day of peak production. This KPI almost made it through the backward selection, but wasn't significant in the end with a P-value of 0,0549. Average day of peak production was 91 days in the dataset. On average cows reach the peak in production already in the 4th week of lactation, while peak in feed intake is reached on average not earlier than week 10 to 12 (Gravert, 1985). In this situation cows reach the unfavourable negative energy balance, which has many negative side effects.

In further research data of more farms should be collected. Favourable would be farms that keep strictly track of health disorders among the cows. With reliable data also the effect of the most important health disorders (mentioned in the literature study) on milk revenue can be measured. Further research should also focus on an American performance indicator. Milk revenue is a good performance indicator but has a few shortcomings, it doesn't take costs into account and leaves even a part of the revenues out of account.

Rumination and eating time can now be measured with the newest available sensors. Based on eating time, feed intake can be determined, and this can create huge possibilities. For example, feed efficiency and energy balance can be calculated when feed intake is available.

Sick can also be expressed as a summation of the total herd hours sick over the last 24 hours. This can give a very accurate and quick view on the health status of the herd. Other interesting options for new KPIs could be in the transition period. There is still much to discover during the transition period, and this study proved that the transition period can have great effect on the following lactation.

6. Conclusions

In this study, 6 KPIs are defined as KPIs with the largest effect on milk revenue. These are the following KPIs, ranked on impact, starting with the KPIs with the most influence on milk revenue:

1. Parity (age)
2. Milk content (fat and protein percentage)
3. Number of metritis treatments
4. Amount of hours sick (pre- and post-partum)
5. Amount of ruminating minutes
6. Amount of eating minutes

Several KPIs which originally also made it through the backward stepwise procedure were left out of this shortlist. Peak SCC, service rate and pre-/post-partum rumination ratio had a much smaller impact on milk revenue and were therefore left out.

A part of this study was focused on creating new KPIs. A combination of two different management programs and available new measured data were used as starting point for new KPIs. Hours sick, rumination minutes and eating minutes were such new KPIs. Already a few of the new KPIs were tested in the analyses. Hours sick pre-partum and hours sick in the first 30 days were taken into account in the shortlist. New KPIs with less economic effect were pre-/post-partum ratio for rumination, eating/rumination ratio and pre-/post-partum ratio for eating.

Further research should focus on the determination of feed intake based on eating time. Determination of feed intake would be a very valuable addition to CowManager.

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