Optimizing selective dry cow therapy using on-line SCC monitoring from an automatic milking system

Minor thesis Business Economics

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Table of content

Abstract

Mastitis is one of the most common health problems in dairy farming. Mastitis causes a lower animal welfare, higher antibiotic use, economic losses due to a poor milk quality and a lower milk yield and less job satisfaction for the dairy farmer. One way to prevent mastitis in cows is to apply dry cow therapy (DCT). Until recently, all cows were dried off using antibiotics. However, there is a growing pressure to reduce the use of antibiotics, as their use may promote antibiotic resistance. One way to reduce antibiotic use during drying off is applying Selective Dry Cow Therapy (SDCT), where the decision to provide DCT is based on cow characteristics such as SCC level at drying off. The directive of the KNMvD is to apply only antibiotics at drying off for primiparous cows with a SCC >150,000 cells/ml and for multiparous cows with a SCC >50,000 cells/ml according to the last milk recording test day up to six weeks before drying off.

Instead of using milk recording test days as decision support tool, another option is to use on-line SCC information from an automatic milking system (AMS). These on-line SCC sensors measure the SCC of a cow every day at every milking. The hypothesis of this study is that monitoring on-line SCC can be a useful tool in the decision support process for applying SDCT and that on-line SCC monitoring has economic benefits over using information from a standard MPR.

The first step in this study was to determine if on-line SCC monitoring before drying off can predict the occurrence of an IMI during the first and first two months of the subsequent lactation. Therefore, this study used data from five commercial Dutch dairy farms that use an on-line SCC monitoring device with an AMS in the period between 1-1-2013 and 17-9-2014. The correlation was determined between the occurrence of an IMI in the subsequent lactation and 15 different explanatory variables based on a combination of five different periods before drying off and three different on-line SCC characteristics during these periods. These three SCC characteristics are, average SCC, standard deviation of SCC and number of milkings in which the SCC exceeded the threshold of >500,000 cells/ml. However the correlation was not significant, the best explanatory variable for multiparous cows was considered to be the average on-line SCC during the last month before drying off and the best explanatory variable for primiparous cows was considered to be the number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off.

The second step was to determine the best selection criteria for SDCT using on-line SCC with the use of a linear programming (LP) model. LP was used to distribute the antibiotics at drying off over different subgroups of cows, with the goal to minimize the total costs related to DCT application and mastitis during the first month of the subsequent lactation, with the restriction of <2.2 Defined Daily Dosage Animal on average per cow. The selection criteria for SDCT as a result of the LP model, is to apply DCT only in multiparous cows with an average SCC between 100,000 and 150,000 or >300,000 cells/ml during the last month before drying off and only in primiparous cows that had one milking that exceeded the threshold of >500,000 cells/ml during the last week before drying off.

The conclusion of this study is that on-line SCC before drying off cannot (yet) predict the occurrence of an IMI in the subsequent lactation, because the correlation between the explanatory variables based on on/line SCC before drying off and the occurrence of an IMI during the first month of the subsequent lactation was too low. Also the prophylactic effect of DCT could not be established for all subgroups of cows in the LP model, whereby no reliable selection criteria could be established based on on-line SCC before drying off. This means that selection criteria using on-line SCC monitoring has not (yet) benefits over selection criteria using MPR. Because lack of required data, the economic value of on-line SCC measurement over MPR could not be determined. More research is needed to predict the occurrence of an IMI in subsequent lactation to determine the best selection criteria for SDCT using data from an AMS, including on-line SCC.

1. Introduction

Udder health is important for cow and farmer. Mastitis is one of the most common health problems in dairy farming. Mastitis causes a lower animal welfare (Schukken et al., 2003), a poor milk quality (Ruegg and Pantoja, 2013), a lower milk yield, higher antibiotic use (Hogeveen et al., 2011) and less job satisfaction for the dairy farmer. Mastitis also causes economic losses, due to reduced milk production and increased treatment costs. In the Netherlands, the losses due to clinical and subclinical mastitis are estimated to vary between €17 and €198 per cow per year, with an average of €78 per cow per year (Hogeveen et al., 2011).

The threshold for Somatic Cell Count (SCC) that is used to diagnose a cow having an intramammary infection (IMI) varies amongst studies. A threshold of approximately 200,000 to 250,000 cells/ml has been considered optimal to reduce diagnostic error under field conditions (Ruegg and Pantoja 2013; Schukken et al. 2003). Pyörälä (2003), Kamal et al. (2014) and Sharma et al. (2011) mention a threshold of 200,000 cells/ml to have the highest sensitivity and specificity for detecting IMI.
The SCC level increases with increasing parity (Sharma et al., 2011) and age (Schukken et al., 2003). Multiparous cows have also a greater cellular response to certain pathogens (Ruegg and Pantoja, 2013). This could be a reason to lower the threshold for primiparous cows to diagnose an IMI. In the Netherlands, a SCC threshold of >250,000 cells/ml is commonly used to diagnose an IMI in multiparous cows, whereas >150,000 cells/ ml is used in primiparous cows (Santman-Berends et al., 2012; Sampimon et al., 2010).
In most studies where the proportion of cows with an IMI in the period after calving is determined, this is based on a milk sample that is taken as part of the milk recording scheme. With an on-line SCC monitoring device, however, the SCC can be measured every milking, whereby also the usual fluctuation in cell counts can be monitored. Therefore, a higher threshold might be more appropriate in the case where on-line SCC measurements are used to detect IMI's. Sharma et al., (2011), Pyörälä (2003) and Schukken et al. (2003) mention a threshold of >500,000 cells/ml to diagnose an IMI based on the SCC measurement.

One way to prevent mastitis in cows is to apply dry cow therapy (DCT), since DCT reduces the occurrence of clinical mastitis in the dry period and during early lactation by removing pre-existing IMI's at drying off and preventing new IMI's during dry period (Bradley and Green 2001; Bhutto et al., 2011; Halasa et al., 2009). In addition, the prophylactic effect of DCT appears to be higher in multiparous than in primiparous cows (Maas, 2014; KNMvD, 2013).
Despite the use of DCT, Bradley and Green (2000) reported that from all mastitis caused by environmental related bacteria occurring in the first 100 days of lactation, 52.6% arose in quarters previously infected, during the dry period, with the same strain of bacteria.

Until recently, all cows were dried off using antibiotics (so called 'Blanket DCT'). However, there is a growing pressure to reduce the use of antibiotics, as their use may promote antibiotic resistance and leave antibiotic residues in the food chain (Bhutto et al., 2011; Berry and Hillerton, 2002). In 2008, the animal production industry in the Netherlands signed a covenant ('Convenant antibioticaresistentie dierhouderij'), to reduce antibiotic resistance and to promote a responsible use of antibiotics in animal husbandry by means of a selective and restrictive use of antibiotics in food-producing animals.
To monitor the use of antibiotics and to compare farms from different animal sectors, the Defined Daily Dosage Animal (DDDA) was introduced. The DDDA indicates for each farm the number of days that an animal on average has been exposed to antibiotics in one year (Autoriteit-Diergeneesmiddelen, 2014).
As a result of the covenant, various efforts were undertaken in the livestock sector. These efforts resulted in a reduction of antibiotic use by 57% in 2013 compared to 2009 in the Netherlands. In 2013, the antibiotic use in dairy cattle was on average 2.8 DDDA. This consisted for 1.8 DDDA (64%)

of antibiotics for drying off and for 0.8 DDDA (29%) of intramammary mastitis injectors. While on average the Dutch dairy achieved the target of <3 DDDA, 45% of the Dutch dairy farms had not. The 25% farms with the highest antibiotic use had a total use of >4 DDDA. This consisted for >2.6 DDDA of antibiotics for drying off and for > 1.1 DDDA of intramammary mastitis injectors. (Autoriteit-Diergeneesmiddelen, 2014). These results imply that there is room to reduce the use of antibiotics for drying off.

One way to reduce antibiotic use during drying off is applying Selective Dry Cow Therapy (SDCT), where the decision to provide DCT is based on cow characteristics such as SCC level at drying off or clinical mastitis history. Only cows with an (history of an) IMI are selected to be treated with antibiotics at drying off (Halasa et al., 2010). A meta-analysis conducted by Halasa et al. (2009) showed that SDCT gives a higher protection against new IMI compared with no DCT but a lower protection compared with blanket DCT. Huijps and Hogeveen (2007) indicated that Blanket DCT is economically beneficial, but SDCT could economically be better in certain situations, depending on the selection procedure for treatment.

The directive of the professional organization of veterinarians in the Netherlands (KNMvD) and the Dutch Animal Health Service is to apply antibiotics at drying off only in those cases when diagnostic research shows that the cow has an IMI. This means that antibiotics will be applied only curatively at drying off. By default, the diagnosis of an IMI is based on SCC. This is measured during milk recording test days up to six weeks before drying off. The directive is to use only antibiotics for primiparous cows with a SCC higher than 150,000 cells/ml and for multiparous cows with a SCC higher than 50,000 cells/ml according to the last milk recording test day prior to drying off (KNMvD, 2013). However, there are two issues suggesting that the 4 to 6 weekly milk recording test days do not provide the most useful information to decide whether or not to apply SDCT.
Firstly, the difference between SCC on the last milk recording test day and the moment of drying off is median 64,000 cells/ml and varies between -171,000 and 999,000 cells/ml. The longer the period between milk recording and drying off moment, the greater the average difference in SCC between these two points in time. This means that SCC increases at the end of the lactation (KNMvD, 2013). This increase is possible due to a lower milk production, which may result in a higher concentration of somatic cells (Green et al, 2006).
Secondly, it is also possible that the situation of the cow changes in the period between the last milk recording and drying off. It is possible that the cow gets an IMI which results in a higher SCC than reported on the last milk recording, or that a cow self-cures from an IMI, resulting in a lower SCC than reported on the last milk recording.

Instead of using milk recording test days as decision support tool, another option is to use on-line SCC information from an automatic milking system (AMS). These on-line SCC sensors measure the SCC of a cow every day at every milking. This means that the SCC of a cow at drying off and the course of the SCC in the period preceding drying off are known. This information could possibly be useful for predicting whether or not mastitis will occur in the subsequent lactation, and therefore, could have the potential to be used as decision support tool to apply SDCT.

Our hypothesis is that monitoring on-line SCC can be a useful tool in the decision support process for applying SDCT. Moreover, on-line SCC monitoring has economic benefits over using information from a standard MPR. To test the hypothesis, three research questions were formulated:

1. Can on-line SCC monitoring before drying off predict the occurrence of an IMI during the first and first two months of the subsequent lactation?
2. What are the best selection criteria for drying off with antibiotics using on-line SCC monitoring?
3. What is the value of on-line SCC monitoring relative to a 4-6 weekly milk recording test scheme?

2. Material and Methods

2.1 Farms

This study used data from five commercial Dutch dairy farms that use an on-line SCC monitoring device with an AMS (Lely industries NV, Maassluis, The Netherlands), and that regularly test new products from the AMS supplier. Data collection started at 1-1-2013, after the test phase of the on-line SCC monitor had finished. Data were collected for each cow for each milking and includes date of drying off, calving date, lactation days, days from dry off, lactation number, date and time of milking, failure milkings, milk yield, milk destination and on-line SCC at whole udder level. The farmers registered cows that were administered DCT. Table 2.1 summarizes general information of the five selected farms.

Table 2.1 General information of the five selected farms

Farm	A	B	C	D	E	Total
Start observation period	1-1-2013	1-1-2013	1-1-2013	1-1-2013	1-1-2013	
End observation period	17-9-2014	17-9-2014	5-5-2014	17-9-2014	17-9-2014	
Herd size at 1-1-2014	136	130	93	109	169	637
Number of AMS units	3	2	2	3	4	14
Number of cows before data selection	155	76	86	127	145	589
Number of cows after data selection	108	49	1	91	102	351

2.2 Data collection and preparation

Only data from no failure milkings (as labelled by the AMS software) were used for this study. Milkings without data for milk yield or with yields <2L have been omitted.
A distinction is made between multiparous and primiparous cows. Primiparous cows had a lactation number of 1 at the moment of drying off. Multiparous cows had a lactation number >1 at the moment of drying off.
The selected cows for this study had an observation period of at least 7 days before and 31 days after the dry period. The selected cows had to had successful on-line SCC measurements for at least one third of their milkings during the first two months after dry period. Table 2.1 summarises the number of cows per farm before and after this selection. Table 2.2 shows the number of cows that were observed for different months after the dry period. For unknown reasons, not all cows were observed for a total of three months after the dry period.

Table 2.2 Number of cows that were observed for different months
After the dry period (DCT=1 means with DCT, DCT=0 means without DCT)

Months after dry period	Primiparous cows		Multiparous cows		Total
	DCT=1	DCT=0	DCT=1	DCT=0	
1	71	44	178	58	351
2	68	39	161	44	312
3	29	16	78	12	135

2.3 Definition of DCT

The farmers recorded data about sick or treated cows in the AMS management system. Data about the application of Dry Cow Therapy (DCT) have been collected through this management system, except for farmer E where DCT data were collected from his own management system (Agrovision). Cows that were recorded as having received DCT at the drying off date or the day before the drying off date were labelled as treated with DCT. All other cows were assumed and labelled as not being

treated with DCT. The dry-off injectors that were used by the farmers included Orbenin dry cow, Orbenin extra dry cow, Prevaclox, Super mastidol and Nafpenzal.

2.4 Definition of IMI

Four different definitions of an intramammary infection (IMI) were defined. They differ in months after the dry period and in threshold of on-line SCC (Table 2.3).

Table 2.3 Definitions and abbreviations of the four used IMI definitions

Abbreviation	Threshold of on-line SCC	Months after dry period
IMI.200.1M	Avg. SCC/day primiparous >150,000 and multiparous >250,000	1
IMI.500.1M	Geometric avg. SCC of three successive milkings >500,000	1
IMI.200.2M	Avg. SCC/day primiparous >150,000 and multiparous >250,000	2
IMI.500.2M	Geometric avg. SCC of three successive milkings >500,000	2

Bradley and Green (2000) reported that from all mastitis caused by environmental related bacteria occurring in the first 100 days of lactation, 52.6% arose in quarters previously infected, during the dry period, with the same strain of bacteria. This result implies that the infection status during the dry period influences the occurrence of mastitis in the first 100 days of the subsequent lactation. This study, therefore, measures the occurrence of IMI within this subsequent lactation. Table 2.2 shows the number of observed cows for 1, 2 and 3 months after the dry period. To have enough observations the occurrence of IMI is measured for one month (IMI.200.1M and IMI.500.1M) and for two months after dry period (IMI.200.2M and IMI.500.2M).

The IMI.200.1M and IMI.200.2M were based on the weighted average on-line SCC per day. In calculating this weighted average, only milkings were included with a value for on-line SCC and milk yield. When a multiparous cow had at least one day in a period of 1 month or 2 months after the dry period a weighted average on-line SCC of >250,000 cells/ml, this cow was labelled with an IMI for this period. For primiparous cows, the threshold of an on-line SCC of >150,000 cells/ml was chosen (Table 2.3).

In this study, the on-line SCC could be determined most milkings by the on-line SCC monitoring device, whereby also the usual fluctuation in cell counts could be monitored. With a single threshold of >150,000 cells/ml for primiparous cows and >250,000 cells/ml for multiparous cows during a period of 1 or 2 months, this could potentially lead to an overestimation of IMI incidents. For this reason, another IMI definition was added using a threshold for on-line SCC of >500,000 cells/ml, which is also used by the AMS supplier to give farmers alerts for a cow that has probably an infection (Table 2.3). Sharma et al., (2011), Pyörälä (2003) and Schukken et al., (2003) also mention a threshold of >500,000 cells/ml to diagnose an IMI.
The IMI.500.1M and IMI.500.2M (Table 2.3) were based on the geometric mean on-line SCC of three successive milkings. This was only possible when for all three successive milkings the on-line SCC was available. When a primiparous or multiparous cow had at least once an average on-line SCC (based on three successive milkings) of >500,000 cells/ml during a period f 1 or 2 months after the dry period, this cow was labelled to have an IMI in this period.

The occurrence of IMI.200.1M and IMI.500.1M could be determined for 351 cows. The occurrence of IMI.200.2M and IMI.500.2M could be determined for 312 cows (Table 2.2). This difference is explained by the 38 cows that were observed the complete first month (all 31 days) after the dry period, but not the entire second month.

2.5 Statistical analyse

To predict the occurrence of an IMI after the dry period, different explanatory variables based on the on-line SCC measurements before the dry period were used. In total, 15 different explanatory variables were used based on on-line SCC properties and the time period before drying off. Five different time periods before drying off were used (1 week, 2 weeks, 1 month, 2 months and 3 months before drying off). For each time period before drying off the 10^{th} logarithm of the weighted average SCC of all successful on-line SCC measurements during these time periods was determined per cow. Also, the standard deviation of these successful on-line SCC measurements during these time periods was determined per cow. Finally the absolute number of milkings during these time periods in which the on-line SCC exceeded the threshold of >500,000 cells/ml were counted per cow. For every explanatory variable only cows were used that were observed for this total period and had at least one successful on-line SCC measurement during this period.

To analyse the relationship between the explanatory variables and the occurrence of an IMI during the subsequent lactation, the Point-Biserial Correlation Coefficient was used. This coefficient is used because the dependent variable, the IMI, is dichotomous and the other, explanatory variable, is continuous. For every combination of IMI-definition (Table 2.3) and explanatory variable this coefficient was determined. This is done for four groups of cows; multiparous cows that received DCT, multiparous cows that received no DCT, primiparous cows that received DCT and primiparous cows that received no DCT.

Also the proportion of cows for which the explanatory variables could be determined is determined for each five time periods before drying off.

2.6 Linear programming model

To determine the best selection criteria to apply SDCT using on-line SCC monitoring, a linear programming (LP) model was used. Linear programming was used to distribute the antibiotics at drying off over different subgroups of cows, with the goal to minimize the total costs related to DCT application and mastitis during the first month of the subsequent lactation.

The 11 subgroups were based on the best explanatory variable based on on-line SCC before drying off to predict the occurrence of mastitis. For multiparous cows this was based on the average on-line SCC during the last month before drying off. For primiparous cows this was based on the amount of milkings with an on-line SCC >500,000 cells/ml. These subgroups are shown in Table 2.4. Each group consists of cows undergoing one out of two activities: they were either dried off with antibiotics or not. Therefore, there were 22 activity levels in the LP model.

Table 2.4 Subgroups used in linear programming model based on parity and average on-line SCC during last month before drying off or amount of milkings with an on-line SCC >500,000 cells/ml during last week before drying off

Subgroup	Parity	Avg. SCC (x 1000 cells/ml)	# milkings with SCC >500,000 cells/ml
Group 1	Multiparous	0-50	
Group 2	Multiparous	50-100	
Group 3	Multiparous	100-150	
Group 4	Multiparous	150-200	
Group 5	Multiparous	200-250	
Group 6	Multiparous	250-300	
Group 7	Multiparous	>300	
Group 8	Primiparous		0
Group 9	Primiparous		1
Group 10	Primiparous		2
Group 11	Primiparous		>2

The LP was applied on an average farm. Data for this average farm came from the farms as shown in Table 2.1. Only primiparous cows were selected that had more than 6 days of lactation before drying off in the dataset. Only multiparous cows were selected that had more than 29 days of lactation before drying off in the dataset. The average on-line SCC and number of milkings with an on-line SCC >500,000 cells/ml of these cows was based on no failure milkings (as labelled by the AMS software) and a milk yield > 2 L. Using this data for every subgroup as shown in Table 2.4 the amount and percentage of cows per subgroup was determined. This result was applied to the LP model to get an average distribution over the subgroups with a total of 100 cows for this average farm.

The costs related to mastitis during the first month of the subsequent lactation were calculated for each of the 22 activity levels. The total costs of the simulated farm were the sum of the total costs related to mastitis of each activity level multiplied by the number of cows per activity level. The costs related to mastitis consist of the costs of DCT and the costs of clinical and subclinical mastitis during the first month of the subsequent lactation. To calculate these costs of clinical and subclinical mastitis for every activity level, the probability of clinical mastitis and the probability of subclinical mastitis were multiplied by the costs for clinical mastitis and the costs of subclinical mastitis.

$$\textit{Total costs of mastitis (i)} =$$
$$\textit{Probability of clinical mastitis (i)} * \textit{Costs of clinical mastitis} +$$
$$\textit{Probability of subclinical mastitis (i)} * \textit{Costs of subclinical mastitis}$$

$$i = \textit{activity level}$$

The costs of clinical mastitis during the first month of lactation was set at €235,- per clinical mastitis case (Hogeveen et al., 2011; Huijps etal., 2008).

The costs of subclinical mastitis consist of milk production losses (Halasa et al., 2007; Halasa et al., 2010; Huijps et al., 2008). Milk production losses due to subclinical mastitis were set at 0.5L/d for primiparous cows and 0.94 L/d for multiparous cows (Halasa et al., 2009). The average duration of subclinical mastitis is 219 days (Halasa et al., 2007). The costs of this milk production loss consist in a non-quota system of the milk-price minus the saved feed (concentrates) costs, when cows are fed in relation to milk production. The milk price was set at €34.50/100 kg milk and the saved concentrate

costs at €5.00/100 kg milk. This combined gives a cost for primiparous cows of €32 and for multiparous cows €61 per subclinical mastitis case. These input values are summarized in Table 2.5.

Costs of subclinical mastitis =
*Milk production losses due to subclinical mastitis (L/day) * Duration milk production losses (days) * (Milk price (€/L) – Saved concentrate costs (€/L milk))*

Table 2.5 Input values for the linear programming model

Parameter	Value
Costs clinical mastitis during first month after dry period	€ 235.00
Costs subclinical mastitis primiparous cow	€ 32.00
Costs subclinical mastitis multiparous cow	€ 61.00
Costs drying off per cow	€ 11.90
Percentage clinical mastitis from total IMI	40 %
Percentage subclinical mastitis from total IMI	60 %
Antibiotics DCT/cow	4 DDDA
Antibiotics clinical mastitis treatment	3 DDDA
Restriction total antibiotic use for DCT and treatment of clinical mastitis during the first month after dry period	2.2 DDDA/cow

Only the probability of an IMI during the first months of the subsequent lactation was available. Because of the large difference in costs for clinical and subclinical mastitis and the used assumption to treat only cows with clinical mastitis a distinction in made between the probability of clinical and subclinical mastitis within each activity level. This study used a ratio of 40% clinical and 60% subclinical mastitis cases of the total IMI cases.

The costs of drying off consist of the costs of the 4 antibiotic injectors and labour costs. Costs of 4 antibiotic injectors was €9.50 (Halasa et al., 2010). Time to apply DCT was 8 min/cow (Halasa et al., 2010) and the hourly wage €18. This leads to a total cost of €11.90 per cow that is administered antibiotics at drying off. These input values are summarized in Table 2.5.

Costs of drying off =
*Costs of 4 antibiotic injector + Hourly wage (€/h) * Required time for drying off (h)*

The LP model divides, per subgroup, the cows between the two available activity levels (apply DCT or not). When the costs related to mastitis and drying off for the activity not to apply DCT are compared to the activity to apply DCT, the cheapest option is economically optimal. The LP finds the optimum distribution of the cows over the activity levels. The solving method used in the LP model was the LP Simplex Engine. The objective function in this LP model was to minimize the total economic costs due to related to DCT application and mastitis during the first month of the subsequent lactation.

$$MIN\ Total\ economic\ costs = \sum_{i=1}^{22} Total\ costs\ of\ mastitis\ (i) * X(i)$$

i = activity level
$X(i)$ = Number of activities (cows) per activity level

In this LP model a restriction is incorporated for the total use of DCT. The restriction of total use of antibiotics for drying off and treatment of mastitis during the first month after calving was set on 220 DDDA for 100 cows (2.2 DDDA per cow). Not the full available 3 DDDA per cow was used, to keep enough possibilities to treat a cow with clinical mastitis after the first month of lactation and to use

antibiotics for other purposes as mastitis and DCT. The total use of antibiotics of the simulated farm was the sum of antibiotic used of each activity level multiplied by the number of cows per activity level.

$$\sum_{i=1}^{22} Antibiotic\ use\ (i) * X(i) \leq Restriction\ in\ total\ use\ of\ antiotics$$

i = activity level
X(i) = Number of activities (cows) per activity level

The use of antibiotics was calculated for every activity level. The antibiotic use for drying off one cow consists of four injectors of antibiotics, one per quarter, which makes it 4 DDDA. It is assumed that treatment of clinical mastitis with antibiotics takes 3 days, which makes it 3 DDDA per clinical mastitis treatment. These input values are shown in Table 2.5. To calculate the use of antibiotics for every activity level, the probability of clinical mastitis was multiplied by the antibiotic use for the treatment of clinical mastitis and summed with the antibiotic use of the application or no application of DCT.

Total antibiotic use (i, with application of DCT) =
*Antibiotic use for drying off + Probability of clinical mastitis (i) * Antibiotic use for treatment*

Total antibiotic use (i, without application of DCT) =
*Probability of clinical mastitis (i) * Antibiotic use for treatment*

i = activity level

As output, the LP model provides the number of cows suffering a clinical or subclinical mastitis, the total amount of antibiotics used for DCT and the treatment of clinical mastitis during the first month of subsequent lactation, the total economic costs related to DCT application and mastitis during the first month of the subsequent lactation, and the number of cows per subgroup which either receive antibiotics or not at drying off.

2.7 Comparison of drying off based on-line SCC and MPR

From 168 cows of farm A, B and D (Table 2.1) the last MPR was available. For these cows was determined whether they had to be dried off with antibiotics according to two selection criteria. The first selection criterion was according to the directive of the professional organization of veterinarians in the Netherlands (KNMvD) and the Dutch GD Animal Health. The directive is to use only antibiotics for primiparous cows with a SCC >150,000 cells/ml and for multiparous cows with a SCC >50,000 cells/ml according to the last milk recording test day (MPR) (KNMvD, 2013). The second selection criterion was according to the result of the LP model. A comparison is made to see to what extent these guidelines match.

3. Results

In total 70.9% of the cows received DCT (249 out of 351 cows). From the primiparous cows 61.7% (71 out of 115) received DCT and from the multiparous cows 75.4% (178 out of 236) received DCT. The average length of the dry period was 54 days and the average lactation length at drying off was 361 days.
During the three months before drying off, the average on-line SCC was 211,600 cells/ml, the average number of milkings per cow was 2.24 and the average milk yield per cow per day was 21.1 kg. During the three months after the dry period the average on-line SCC was 213,500 cells/ml, the average number of milkings per cow was 3.25 and the average milk yield per cow per day was 39.4 kg. The average milk yield per cow at drying off was 8.8 kg. In the 3 days preceding drying off the average milk yield per cows per day was 11.0 kg. The average milk yield per cow during the week preceding drying off was 11.9 kg.
Table 3.1 shows the percentage of cows that incurred an IMI (using four definitions of IMI; Table 2.3) in the subsequent lactation. This is presented for primiparous and multiparous cows that received or did not receive DCT.
Not all milkings had an on-line SCC measurement available. Table 3.2 shows the percentage of the observed milkings with an available on-line SCC. So, from all the milkings from all the cows during the three months before the dry period, 68.3% had a successful on-line SCC measurement, 31.7% had not. During the three months after the dry period, 71.8% of all cow milkings had a successful on-line SCC measurement.

Table 3.1 Percentage of cows with (DCT=1) and without DCT (DCT=0) that incurs an IMI according to different IMI definitions

	Primiparous cows		**Multiparous cows**		**Total**
	DCT=1	**DCT=0**	**DCT=1**	**DCT=0**	
IMI.200.1M (%)	67.61	65.91	78.09	74.14	73.79
IMI.500.1M (%)	14.08	18.18	36.52	31.03	28.77
IMI.200.2M (%)	82.35	76.92	87.58	81.82	84.29
IMI.500.2M (%)	16.18	20.51	39.75	29.55	30.77

Table 3.2 Percentage of observed milkings with available on-line SCC (DCT=1 means with DCT, DCT=0 means without DCT)

	Available on-line SCC (%)
3 months before the dry period	68.3
Milkings of primiparous cows DCT=1	71.4
Milkings of primiparous cows DCT=0	58.1
Milkings of multiparous cows DCT=1	70.0
Milkings of multiparous cows DCT=0	66.7
3 months after the dry period	71.8

3.1 Predicting an IMI with on-line SCC monitoring

Tables 3.3 through 3.6 demonstrate the biserial correlation coefficient between the 15 explanatory on-line SCC variables and the four different IMI definitions for primiparous cows with DCT, primiparous cows without DCT, multiparous cows with DCT and multiparous cows without DCT, respectively. For every combination each table also provides the number of observed cows. Also the average correlation coefficient is represented for every explanatory variable (row) and every IMI definition (column). None of the biserial correlations were significant.

Table 3.3 Biserial correlation coefficient of different explanatory on-line SCC variables and different IMI definitions and the average per row and column for primiparous cows with DCT

Primiparous DCT=1	IMI.200.1M	IMI.500.1M	IMI.200.2M	IMI.500.2M	Average row
1 week (obs.)	**66**	**66**	**63**	**63**	
Average	0.195	0.206	0.154	0.293	0.212
SD	0.215	0.151	0.204	0.305	0.219
#>500	0.114	0.312	0.116	0.310	0.213
2 weeks (obs.)	**68**	**68**	**65**	**65**	
Average	0.165	0.213	0.151	0.268	0.199
SD	0.222	0.168	0.212	0.268	0.218
#>500	0.153	0.299	0.131	0.299	0.221
1 month (obs.)	**66**	**66**	**63**	**63**	
Average	0.074	0.209	0.034	0.228	0.136
SD	0.060	0.118	-0.071	0.163	0.068
#>500	0.010	0.257	-0.098	0.241	0.102
2 months (obs.)	**64**	**64**	**61**	**61**	
Average	0.041	0.195	-0.045	0.234	0.106
SD	0.021	0.086	-0.110	0.131	0.032
#>500	0.013	0.307	-0.116	0.296	0.125
3 months (obs.)	**58**	**58**	**56**	**56**	
Average	0.056	0.240	-0.012	0.244	0.132
SD	0.094	0.151	-0.051	0.135	0.082
#>500	0.128	0.431	-0.006	0.360	0.228
Average column	0.104	0.223	0.033	0.252	

Table 3.4 Biserial correlation coefficient of different explanatory on-line SCC variables and different IMI definitions and the average per row and column for primiparous cows without DCT

Primiparous DCT=0	IMI.200.1M	IMI.500.1M	IMI.200.2M	IMI.500.2M	Average row
1 week (obs.)	**35**	**35**	**30**	**30**	
Average	0.034	0.144	0.094	0.083	0.089
SD	0.291	0.154	0.281	0.139	0.216
#>500	0.247	0.195	0.213	0.167	0.205
2 weeks (obs.)	**38**	**38**	**33**	**33**	
Average	0.074	0.023	0.142	-0.046	0.048
SD	0.202	0.028	0.174	0.005	0.102
#>500	0.160	0.072	0.120	0.027	0.095
1 month (obs.)	**44**	**44**	**39**	**39**	
Average	0.245	0.015	0.166	-0.041	0.096
SD	0.195	-0.041	0.130	-0.060	0.056
#>500	0.158	0.025	0.097	-0.024	0.064
2 months (obs.)	**44**	**44**	**39**	**39**	
Average	0.296	0.012	0.282	-0.023	0.142
SD	0.108	-0.093	0.142	-0.130	0.007
#>500	0.168	-0.035	0.135	-0.089	0.045
3 months (obs.)	**37**	**37**	**33**	**33**	
Average	0.463	0.215	0.411	0.191	0.320
SD	0.180	0.060	0.212	0.022	0.118
#>500	0.206	0.075	0.199	0.019	0.125
Average column	0.202	0.057	0.186	0.016	

Table 3.5 Biserial correlation coefficient of different explanatory on-line SCC variables and different IMI definitions and the average per row and column for multiparous cows with DCT

Multiparous DCT=1	IMI.200.1M	IMI.500.1M	IMI.200.2M	IMI.500.2M	Average row
1 week (obs.)	**159**	**159**	**145**	**145**	
Average	0.153	0.291	0.329	0.283	0.264
SD	0.089	0.260	0.201	0.219	0.192
#>500	0.064	0.246	0.181	0.229	0.180
2 weeks (obs.)	**165**	**165**	**151**	**151**	
Average	0.154	0.282	0.300	0.285	0.255
SD	0.058	0.188	0.176	0.151	0.143
#>500	0.090	0.219	0.194	0.211	0.179
1 month (obs.)	**172**	**172**	**155**	**155**	
Average	0.139	0.314	0.323	0.334	0.278
SD	0.075	0.237	0.252	0.225	0.197
#>500	0.114	0.190	0.199	0.196	0.175
2 months (obs.)	**163**	**163**	**146**	**146**	
Average	0.151	0.302	0.273	0.318	0.261
SD	0.143	0.291	0.251	0.280	0.241
#>500	0.127	0.219	0.212	0.212	0.192
3 months (obs.)	**137**	**137**	**126**	**126**	
Average	0.122	0.229	0.237	0.226	0.204
SD	0.139	0.208	0.257	0.172	0.194
#>500	0.086	0.196	0.192	0.183	0.164
Average column	0.114	0.245	0.238	0.235	

Table 3.6 Biserial correlation coefficient of different explanatory on-line SCC variables and different IMI definitions and the average per row and column for multiparous cows without DCT

Multiparous DCT=0	IMI.200.1M	IMI.500.1M	IMI.200.2M	IMI.500.2M	Average row
1 week (obs.)	**52**	**52**	**41**	**41**	
Average	0.3529	0.3297	0.0735	0.2812	0.259
SD	0.0917	0.2243	-0.1156	0.2259	0.107
#>500	0.1413	0.3527	-0.0458	0.3127	0.190
2 weeks (obs.)	**53**	**53**	**42**	**42**	
Average	0.2591	0.4269	0.1666	0.3399	0.298
SD	0.1079	0.2549	-0.0091	0.2511	0.151
#>500	0.1573	0.3966	0.0350	0.3692	0.240
1 month (obs.)	**57**	**57**	**44**	**44**	
Average	0.1371	0.4721	0.1085	0.3422	0.265
SD	0.1064	0.2702	-0.0399	0.1961	0.133
#>500	0.1237	0.3278	0.0110	0.2781	0.185
2 months (obs.)	**55**	**55**	**41**	**41**	
Average	0.0235	0.5019	0.0510	0.4466	0.256
SD	0.0957	0.2956	-0.0238	0.2694	0.159
#>500	0.0651	0.3776	0.0118	0.3603	0.204
3 months (obs.)	**41**	**41**	**31**	**31**	
Average	0.0556	0.4516	0.1063	0.4920	0.276
SD	0.1309	0.3065	0.0501	0.4384	0.231
#>500	0.0673	0.3725	0.0905	0.5087	0.260
Average column	0.128	0.357	0.031	0.341	

Table 3.7 shows the number of primiparous and multiparous cows that had at least one third of their milkings a successful on-line SCC measurements during 1 or 2 months after the dry period and with at least one successful on-line SCC measurement during 1 week, 2 weeks, 1 month, 2 months, or 3 months before drying off. With this data, the coverage ratio from the total primiparous and respectively multiparous cows is calculated. So from the 115 primiparous cows that were observed for 1 month after the dry period and for which the occurrence or non-occurrence of IMI.200.1M and IMI.500.1M were determined. 101 primiparous cows had at least one successful on-line SCC measurement during the first week before the dry period. This means that for 87.7% (coverage ratio) of the primiparous cows the three explanatory variables (average, SD, and #>500) with a period of one week before the dry period could be determined. The coverage ratio of 2 and 3 months before drying off is lower than the coverage ratio of 1 month before drying off. This is due to cows that are not observed the entire period of 2 or 3 months before drying off.

Table 3.7 Number of primiparous and multiparous cows that were observed for 1 and 2 months after the dry period that had at least one successful on-line SCC measurement in the periods before drying off and the coverage ratio of the total primiparous and multiparous cows, respectively

		Observation after dry period			
		1 month		2 months	
Period before drying off		**Primiparous N=115**	**Multiparous N=236**	**Primiparous N=107**	**Multiparous N=205**
1 week	Number (N)	101	211	93	186
	Coverage ratio (%)	87.8	89.4	86.9	90.7
2 weeks	Number (N)	106	218	98	193
	Coverage ratio (%)	92.2	92.4	91.6	94.1
1 month	Number (N)	110	229	102	199
	Coverage ratio (%)	95.7	97.0	95.3	97.1
2 months	Number (N)	108	218	100	187
	Coverage ratio (%)	93.9	92.4	93.5	91.2
3 months	Number (N)	95	178	89	157
	Coverage ratio (%)	82.6	75.4	83.2	76.6

To determine the best explanatory variable for primiparous and multiparous cows, a consideration was made between coverage ratio, highest correlation coefficients and highest average correlations coefficients for the different explanatory variables and for the IMI definitions. This consideration was done for both the groups with and without DCT and compared with each other, to determine the best explanatory variable which has in both groups a high correlation coefficient. The best explanatory variable for multiparous cows was considered to be the average on-line SCC during the last month before drying off. The best explanatory variable for primiparous cows was considered to be the number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off. The best correlation of these explanatory variables was with the IMI definition IMI.500.1M. Scatter plots of the relationship between these best explanatory variables and IMI.500.1M are shown in figure 3.1 for primiparous cows and in figure 3.2 for multiparous cows. Table 3.8 reports from which farms the cows originate on which these correlations are based.

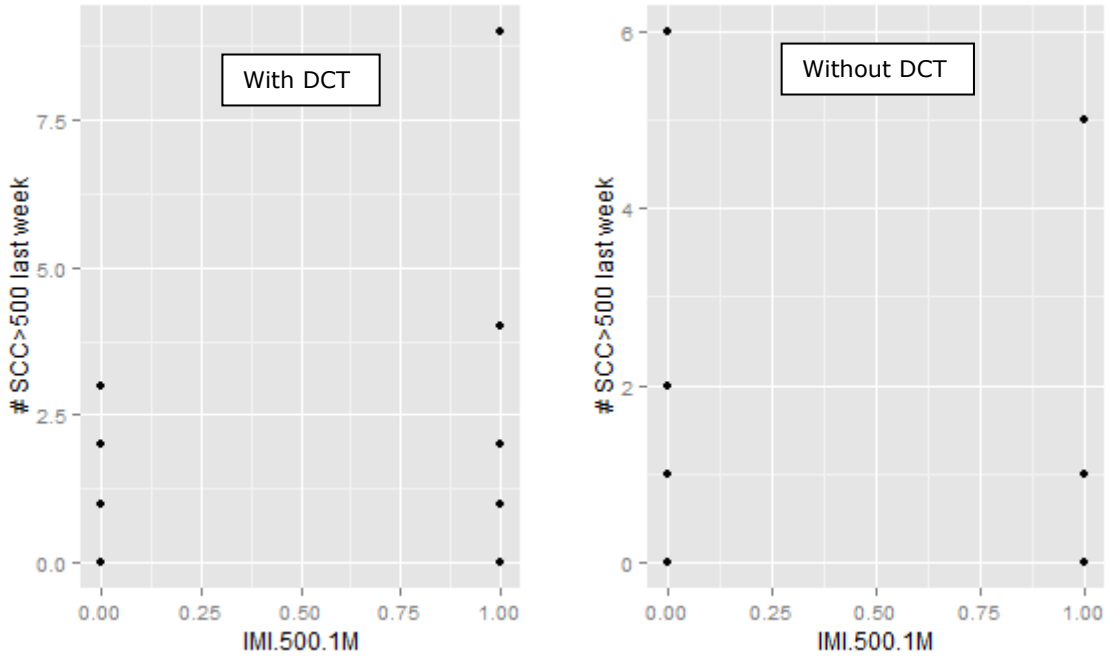

Figure 3.1 The relationship between the number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off and the occurrence of IMI.500.1M for primiparous cows. IMI.500.1M means at least one geometric average SCC of three successive milkings >500,000 cells/ml, within *the first month of the subsequent lactation. (Left with DCT, right without DCT)*

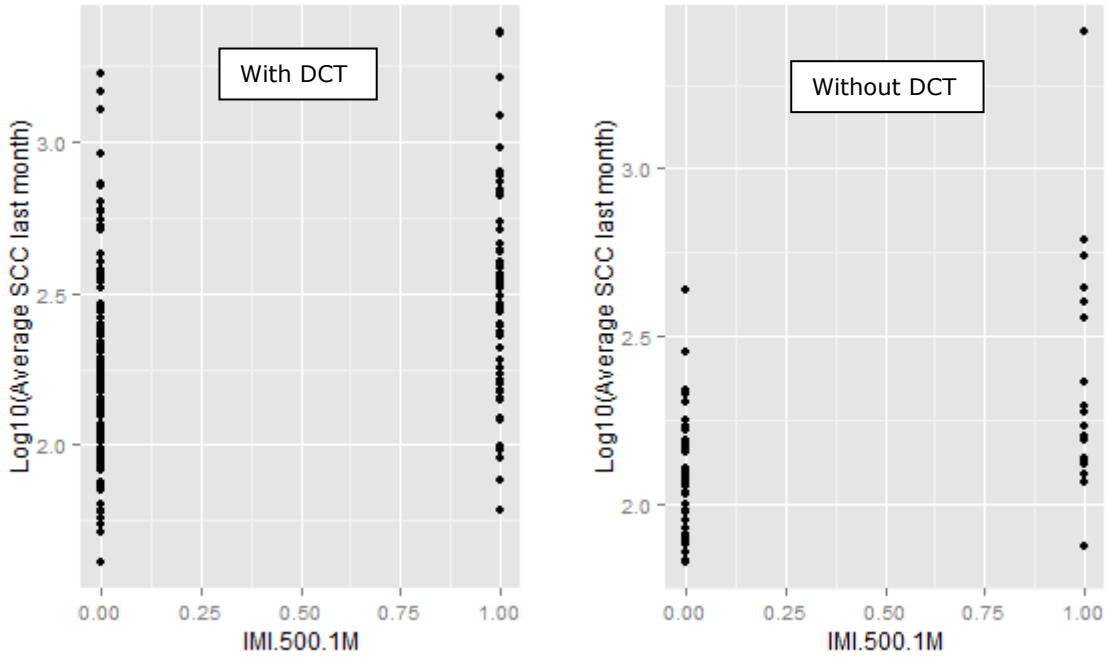

Figure 3.2 The relationship between log10 of the average on-line SCC in the last month before drying off and the occurrence of IMI.500.1M for multiparous cows. IMI.500.1M means at least one geometric average SCC of three successive milkings >500,000 cells/ml, within *the first month of the subsequent lactation (Left with DCT, right without DCT).*

Table 3.8 Number of primiparous cows per farm that were available to determine the relationship between the number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off and the occurrence of an IMI in the first month of the subsequent lactation and number of multiparous cows per farm that were available to determine the relationship between the average on-line SCC in the last month before drying off and the occurrence of an IMI in the first month of the subsequent lactation.

		Farms					
Cows		**A**	**B**	**C**	**D**	**E**	**Total**
Primiparous	DCT=0	14	2	0	3	16	35
	DCT=1	10	8	0	20	28	66
Multiparous	DCT=0	40	4	0	5	8	57
	DCT=1	41	33	0	54	44	172
Total		105	47	0	82	96	330

3.2 Determining the best selection criteria for SDCT using on-line SCC

Table 3.9 shows different subgroups of primiparous cows, based on the number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off. Per subgroup the number of observations of primiparous cows that received (DCT=1) or did not receive DCT (DCT=0) at drying off is shown and the percentage of these primiparous cows that incurred an IMI during the first month of the subsequent lactation. Figure 3.3 shows the number of observations from Table 3.9 in a bar graph. Figure 3.4 shows the occurrence of IMI from Table 3.9 in a bar graph. Both figures 3.3 and 3.4 do this for primiparous cows that received and did not receive DCT at drying off. In both figures the subgroups of 3 to 9 number of milkings (Table 3.9) are combined in one subgroup of >2 milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off. This is done to increase the number observations in this subgroup and have at least one observation in this subgroup for both groups of primiparous cows that received and did not receive DCT at drying off.

Table 3.10 shows the same information as 3.9 but then for multiparous cows. Here the subgroups are based on the average on-line SCC during the last month before drying off. Also this table is translated into two bar charts in figure 3.5 and 3.6 that show the number of observations and the occurrence of IMI per subgroup. In these bar charts the subgroup of multiparous cows with an average SCC >300,000 cells/ml is combined from the three subgroups from Table 3.8 with an average SCC >300,000.

Table 3.9 The occurrence of IMI.500.1M per amount of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off for primiparous cows without (DCT=0) and with DCT (DCT=1) and the number of observation where this is based on

# milkings	DCT=0		DCT=1	
SCC >500,000	Obs.	IMI (%)	Obs.	IMI (%)
0	30	13	44	14
1	1	100	15	7
2	1	0	3	33
3	0	-	2	0
4	0	-	1	100
5	1	100	0	-
6	1	0	0	-
7	0	-	0	-
8	0	-	0	-
9	0	-	1	100
Total	34		66	

Table 3.10 The occurrence of IMI.500.1M per subgroup categorized by average on-line SCC during the last month before drying off for multiparous cows without (DCT=0) and with DCT (DCT=1) and the amount of observations where this is based on

	DCT=0		DCT=1	
SCC (cells/ml)	Obs.	IMI (%)	Obs.	IMI (%)
0 - 50	0	-	2	0
50 - 100	14	21	28	18
100 - 150	20	30	32	13
150 - 200	11	18	24	42
200 - 250	4	25	18	39
250 - 300	1	0	13	54
300 - 350	0	-	6	67
350 - 400	0	-	12	58
>400	7	86	37	54
	57		172	

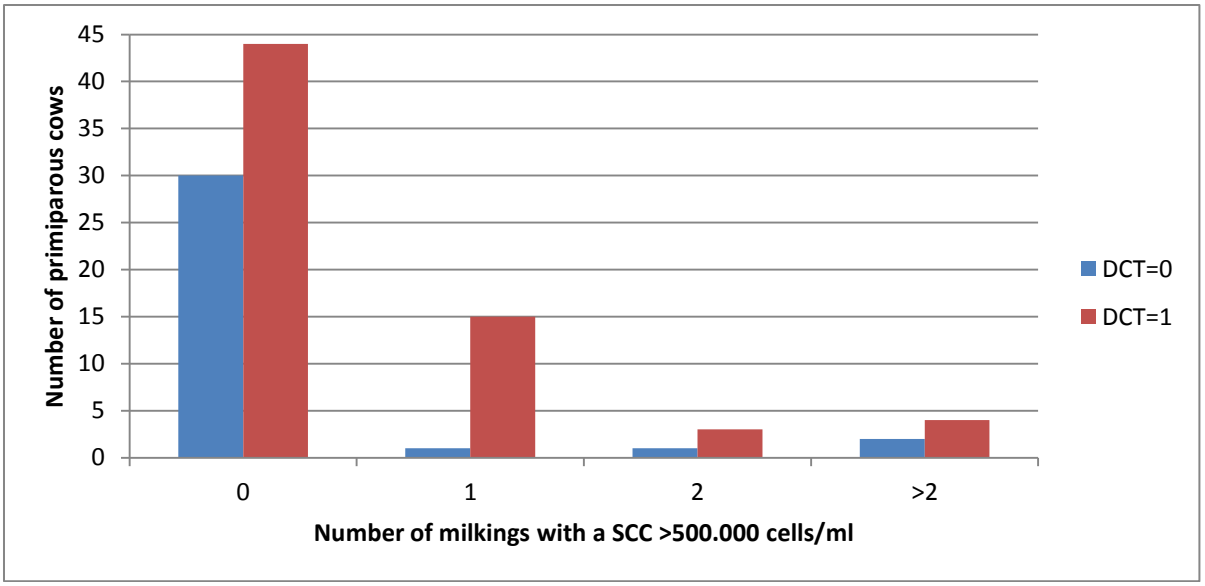

Figure 3.3 Number of primiparous cows per number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off (DCT=1 means with DCT, DCT=0 means without DCT)

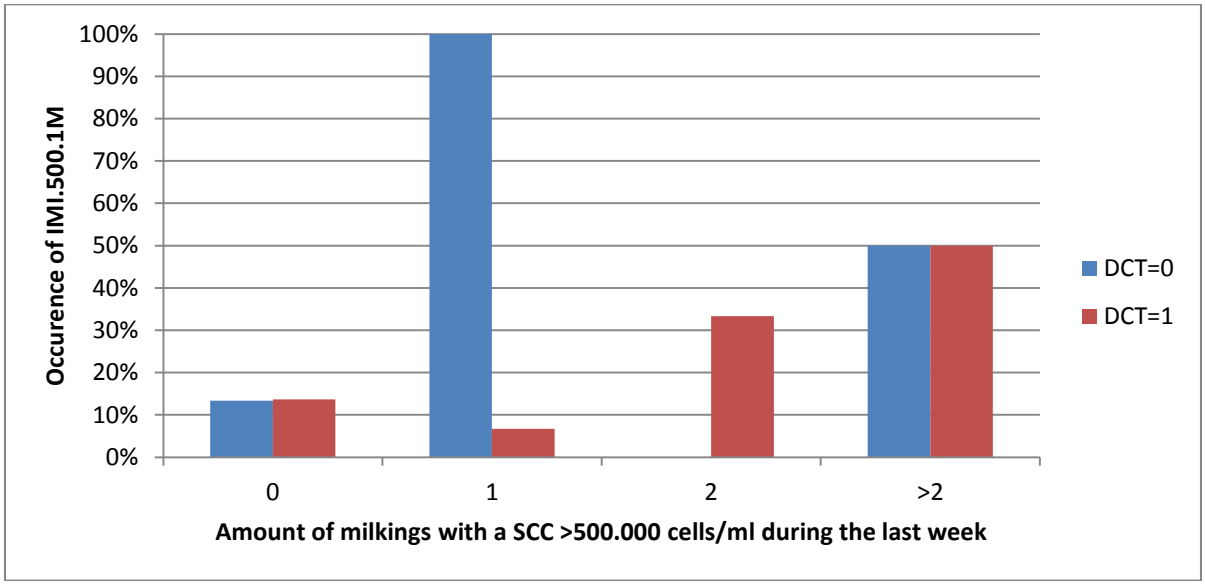

Figure 3.4 The occurrence of an IMI in the first month after dry period in primiparous cows per amount of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off (DCT=1 means with DCT, DCT=0 means without DCT)

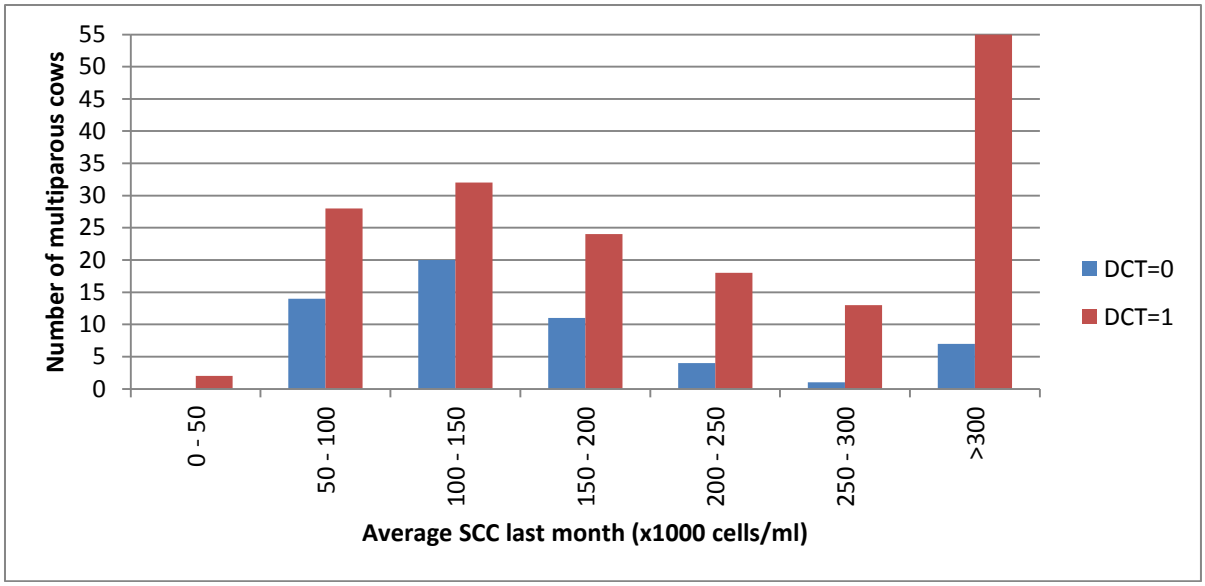

Figure 3.5 Number of multiparous cows per subgroup categorized by average on-line SCC during the last month before drying off (DCT=1 means with DCT, DCT=0 means without DCT)

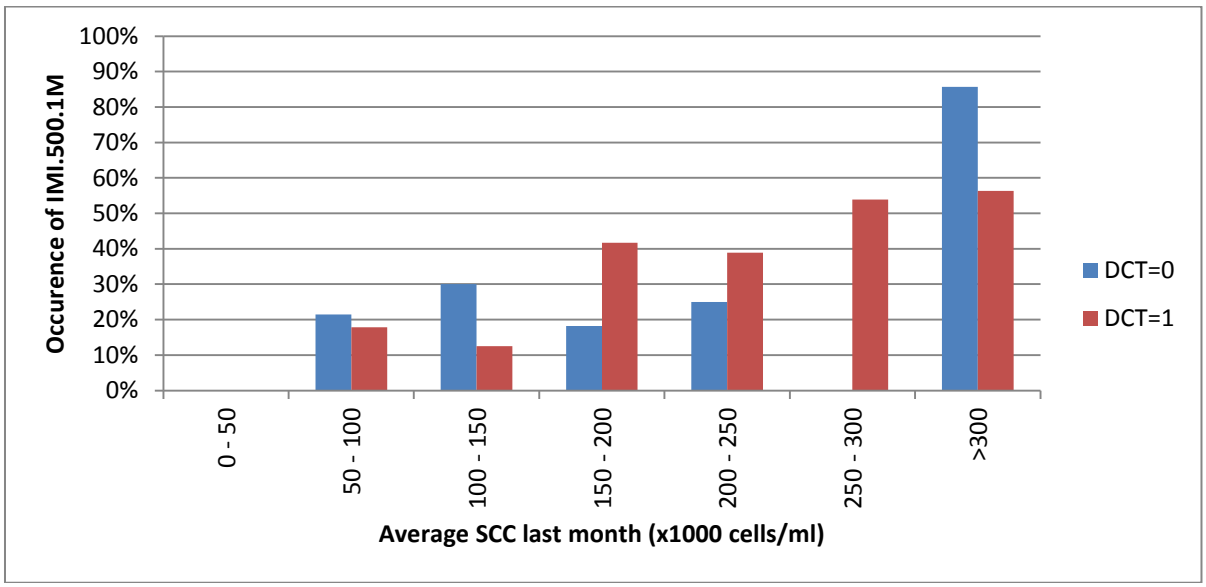

Figure 3.6 The occurrence of an IMI in the first month after dry period in multiparous cows per subgroup categorized by average on-line SCC during the last month before drying off (DCT=1 means with DCT, DCT=0 means without DCT)

Table 3.11 shows the different subgroups based on parity (primi- vs. multiparous) and average SCC during the last month before drying off for multiparous cows or number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off for primiparous cows. These subgroups are used in the LP model. Per subgroup the number and percentage of cows is presented. These percentages are used in the LP model to represent an average Dutch farm.

Table 3.11 Distribution of cows among different subgroups based on parity and average on-line SCC during last month before drying off or number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off

Subgroup	Parity	Average SCC (x 1000 cells/ml)	# milkings SCC >500,000 cells/ml	Cows in dataset N	%
Group 1	Multiparous	0-50		2	0.5
Group 2	Multiparous	50-100		61	14.0
Group 3	Multiparous	100-150		73	16.7
Group 4	Multiparous	150-200		45	10.3
Group 5	Multiparous	200-250		31	7.1
Group 6	Multiparous	250-300		19	4.4
Group 7	Multiparous	>300		81	18.6
Group 8	Primiparous		0	92	21.1
Group 9	Primiparous		1	21	4.8
Group 10	Primiparous		2	4	0.9
Group 11	Primiparous		>2	7	1.6
			Total cows	436	100

Table 3.12 shows the optimized SDCT to reach the lowest total costs, using the constraint of a DDDA of maximal 2.2 DDDA/cow using LP. This table shows the different subgroups with their characteristics in parity, average SCC during last month before drying off (for multiparous cows) or number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off (for primiparous cows). The row 'Cows in group (Total=100)' shows the number of cows in each subgroup on an average farm (from Table 3.11). These columns of subgroups are divided in two columns of activity. The activities are that a cows within a subgroup receive DCT (DCT=Yes) or do not receive DCT (DCT=No). Per activity are shown, the IMI probability (based on Tables 3.9 and 3.10 and figures 3.3 to 3.6), clinical mastitis probability (40% of IMI probability) and subclinical mastitis probability (60% of IMI probability) during the first month after dry period. Also the amount of administered antibiotics for DCT and clinical mastitis treatment and the cost per cow are shown per activity. The bottom row (Activity number) shows the number of cows per subgroup which either receive DCT or not after linear programming. This means for instance that to reach the lowest total cost, in subgroup 3 all 16.7 cows in this subgroup has to be dried off with DCT. This gives the optimal distribution of the cows over the different activities and reflects the optimized SDCT that minimize total costs.

The result of the LP model is to apply DCT to subgroups 3, 7 and 9. In these subgroups the probability of an IMI, and the associated mastitis costs, are much lower when applying DCT that it is economically profitable to apply DCT. In subgroup 2 the probability of an IMI when applying DCT is also lower, but the difference in IMI probability, and associated mastitis costs, is not that big, that the declining effect in mastitis costs, can make the costs of applying DCT profitable.

In subgroups 1 and 11 the probability of an IMI is in both situation of applying and not applying DCT the same, so it won't be profitable to apply DCT with the associated costs.

In subgroup 4, 5, 6, 8 and 10 the probability of an IMI is higher in the situation of applying DCT. This makes not applying DCT more profitable, because of lower mastitis costs and saving costs of applying DCT.

Table 3.12 Optimized selective dry cow therapy to reach lowest total costs and a total DDDA of maximal 2.2 DDDA/cow using linear programming

	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7		Group 8		Group 9		Group 10		Group 11	
Parity	Multiparous		Multiparous		Multiparous		Multiparous		Multiparous		Multiparous		Multiparous		Primiparous		Primiparous		Primiparous		Primiparous	
Avg. on-line SCC (*1000 cells/ml)	0-50		50-100		100-150		150-200		200-250		250-300		>300									
#milkings on-line SCC>500,000															0		1		2		>2	
Cows in group (Total=100)	0.5		14.0		16.7		10.3		7.1		4.4		18.6		21.1		4.8		0.9		1.6	
DCT	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
IMI (probability, %)	0.0	0.0	17.9	21.4	12.5	30.0	41.7	18.2	38.9	25.0	53.8	0.0	56.4	85.7	13.6	13.3	6.7	100	33.3	0.0	50.0	50.0
Clinical mastitis (probability, %)	0.0	0.0	7.2	8.6	5.0	12.0	16.7	7.3	15.6	10.0	21.5	0.0	22.6	34.3	5.4	5.3	2.7	40.0	13.3	0.0	20.0	20.0
Subclinical mastitis (probability, %)	0.0	0.0	10.7	12.8	7.5	18.0	25.0	10.9	23.3	15.0	32.3	0.0	33.8	51.4	8.2	8.0	4.0	60.0	20.0	0.0	30.0	30.0
Use of antibiotic doses	4.00	0.00	4.21	0.26	4.15	0.36	4.50	0.22	4.47	0.30	4.65	0.00	4.68	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costs (€/cow)	11.90	0.00	35.28	27.95	28.23	39.18	66.36	23.77	62.70	32.65	82.16	0.00	85.56	111.9	27.30	15.06	19.48	113.2	49.60	0.00	68.50	56.60
Activity number (cows)	0.0	0.5	0.0	14.0	16.7	0.0	0.0	10.3	0.0	7.1	0.0	4.4	18.6	0.0	0.0	21.1	4.8	0.0	0.0	0.9	0.0	1.6

Table 3.13 Selection criteria for selective dry cow therapy

Multiparous cows (average on-line SCC during the last month before drying off)		Primiparous cows (# milkings with a on-line SCC >500,000 cells/ml during the last week before drying off)	
Without DCT	With DCT	Without DCT	With DCT
0 – 50,000		0	
50,000 – 100,000			1
	100,000 – 150,000	2	
150,000 – 200,000		>2	
200,000 – 250,000			
250,000 – 300,000			
	>300,000		

In the optimized situation, the antibiotic use is 1.6 DDDA/cow, which does not reach the restriction in antibiotic use of 2.2 DDDA/cow (Table 3.12). This means that this restriction in antibiotic use was not an obstacle to reach the lowest total costs. After optimization the total costs of clinical and subclinical mastitis during the first month after dry period and drying off was €34.32 per cow and 9.3% of the cows will suffer from clinical mastitis and 13.9% of the cows will suffer from subclinical mastitis during the first month after dry period.

The optimal selection criteria to apply SDCT, resulting from this linear programming model are summarized in Table 3.13. This means that only multiparous cows with an average on-line SCC during the last month before drying off between 100,000 and 150,000 cells/ml or >300,000 cells/ml will receive DCT. From the primiparous cows, only cows with 1 milking during the last week before drying off that exceeded the threshold of >500,000 cells/ml will receive DCT.

3.3 Compare selection criteria based on on-line SCC and 4-6 weekly MPR

Table 3.14 summarizes the number of cows that will receive DCT based on the selection criteria from the LP result (Table 3.13), or based on the directives of the KNMvD. In 61.9% of the cows, both selection criteria gave the same result (Table 3.14). According to the directives of the KNMvD using the last milk recording test day, more cows are dried off than according to the result of the LP model based on on-line SCC. The group of cows that is dried off based on last milk recording test day and not when based on on-line SCC (30.4%) is bigger than the group of cows that is dried off based on on-line SCC and not when based on last milk recording test day (7.7%).

Table 3.15 summarizes the number of cows that will receive DCT based on the LP selection criteria and those that actually received DCT as recorded by the farmers in a cross table.

Table 3.16 summarizes the number of cows that will receive DCT based on the last milk recording test day using the KNMvD directive and those that actually received DCT as recorded by the farmers in a cross table. In 63.1% of the cows, SDCT was applied by the farmers as advised by the selection criteria based on the last milk record day using the KNMvD directive.

Table 3.14 Cross table that shows the amount of cows and the percentage of the total cows (N=168) that are or are not dried off using the selection criteria from the LP result based on on-line SCC and the KNMvD directive based on the last milk recording test day (MPR)

		Drying off using MPR	
		No	Yes
Drying off using on-line SCC monitoring	No	45 26.8%	51 30.4%
	Yes	13 7.7%	59 35.1%

Table 3.15 Cross table that shows the amount of cows and the percentage of the total cows (N=168) that are or are not dried off using the selection criteria from the LP result based on-line SCC and the actual dried off cows by farmers decision

		Dried off by farmer	
		No	Yes
Drying off using on-line SCC monitoring	No	44 26.2%	52 31.0%
	Yes	18 10.7%	54 32.1%

Table 3.16 Cross table that shows the amount of cows and the percentage of the total cows (N=168) that are or are not dried off using the selection criteria of the KNMvD directive based on the last milk recording test day (MPR) and the actual dried off cows by farmers decision

		Drying off using MPR	
		No	Yes
Dried off by farmer	No	29	33
		17.3%	19.6%
	Yes	29	77
		17.3%	45.8%

4. Discussion

4.1 IMI definition

Increased SCC can be used as an indicator of an IMI, but it can't distinguish infected from uninfected udders (Schukken et al., 2003). Only bacteriological examination can diagnose an infection more accurately (Pyörälä, 2003; Schukken et al., 2003). This bacteriological information, however, was not available for this research. Somatic cells are a reflection of the inflammatory response to an IMI. SCC is commonly used as a reflection of the udder health status of a cow, although they do not truly identify an IMI. The most accurate relationship between IMI and SCC exists at quarter level (Schukken et al., 2003). However, since SCC at quarter level was not available, this study used on-line SCC at udder level to define IMI.
A threshold of approximately 200,000 to 250,000 cells/ml has been considered optimal to reduce diagnostic error under field conditions (Ruegg and Pantoja, 2013; Sharma et al., 2011; Kamal et al., 2014). Using the threshold for an IMI of an average on-line SCC >150,000 cells/ml per day for primiparous and >250,000 cells/ml for multiparous cows, this research found that 73.8% of the primiparous and multiparous cows incurs at least one IMI during the first month after calving and 84.3% incurs at least one IMI during the first two months after calving.

Several studies determined the prevalence of subclinical mastitis, but they have a large variation in results. Santman-Berends et al., (2012) mentioned that 25.5% of the primiparous cows has clinical mastitis in the first 100 days in lactation based on a SCC >150,000 cells/ml, monthly measured. Maas (2014) found a probability of 4.8 - 19.0% for primiparous cows for getting subclinical mastitis and 9.1 – 18.2% for getting clinical mastitis during the first 100 days in lactation. For multiparous cows, the probability was 7.3 – 31.7% for getting subclinical, and 9.0 – 26.8% for getting clinical mastitis during the same period.
Owens et al., (2001) found that 56.5% of the quarters of 233 investigated Jersey primiparous cows were infected. Van den Borne et al. (2008) found a subclinical mastitis prevalence of 13.2% for primiparous and 27.6% for multiparous cows. This was measured as the proportion of cows with an udder SCC >200,000 cells/ml. Van den Borne et al. (2008) mentioned a subclinical mastitis incidence rate of 1.17/365 days for multiparous and 0.81/365 days for primiparous cows. This means that if a cow would be in lactation for 365 consecutive days she would have, on average, 1.17 new subclinical mastitis cases during that lactation. Sampimon et al. (2008) sampled 11,225 quarters from 2,873 cows of which 41% had a SCC > 200,000 cells/ml. Bacterial growth occurred in 37% of these milk samples with elevated SCC levels.
Compared with these reported results, the prevalence of IMI's found in my research using the threshold of a SCC >150,000 and > 250,000 cells/ml for primiparous and multiparous cows respectively seem overestimated.
A reason could be the use of on-line SCC as indicator for IMI. The SCC is not exclusively influenced by IMI. Usually, there are fluctuations in SCC. This means that cows regularly can have a SCC above 250,000 cells/ml without having an IMI (Schukken et al., 2003). Other non-infectious factors as age, breed, lactation stage, measurement equipment, fraction of milk sample, season, diurnal variation and number of quarters with an IMI (in composite samples) also have impact on the SCC (Djabri et al., 2002; Ruegg and Pantoja, 2013; Schukken et al., 2003). Sampimon et al. (2009) sampled quarter milk of 408 multiparous and 145 primiparous cows with a SCC >250,000 cells/ml and >150,000 cells/ml respectively. Bacterial growth occurred in 37.3% of these milk samples with a high SCC. Also, the quarters of 519 multiparous and primiparous cows with a lower SCC were sampled. Bacterial growth occurred in 21.1% of these milk samples with a low SCC.
Using an on-line SCC measuring device, 72% of all milkings had SCC determined (Table 3.2). This leads to more SCC measurements than using the usual milk recording frequency of every four to six weeks, used in most studies. So the chance was higher that all incurred IMI's could be detected, whereas in the other studies the IMI's during the four weeks that the milk was not recorded were missed, which

leads to an underestimation of the amount of IMI's in the other studies, and a more reliable amount of IMI in this study. Contrasting with that, on-line SCC-measurement also provides information on the normal daily fluctuations of SCC that are not due to an IMI are recorded, which may have lead to an overestimation of the IMI-cases.
To limit the overestimation of IMI-cases, an alternative threshold of a geometric average of >500,000 cell/ml of three successive milkings was used in this research. Sharma et al. (2011), Pyörälä (2003) and Schukken et al. (2003) mention a threshold of >500,000 cells/ml to diagnose an IMI.
Using this threshold, this research found that 28.8% of the primiparous and multiparous cows incur at least one IMI during the first month after calving and 30.8% incurs at least one IMI during the first two months after calving. These incidence rates of IMI's seem more equal to in above mentioned studies.

4.2 Low correlation between IMI occurrence and explanatory variables

Within the groups of primiparous cows (with or without DCT and with or without an IMI) there was a large variation in number of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off. Within the groups of multiparous cows there was a large variation in the average SCC during the last month before drying off. This large variation resulted in no significant correlations between the explanatory variables before drying off based on on-line SCC and the occurrence of an IMI after dry period.
This large variation could have different reasons, including the erroneous assignment of cows and heifers to be in the wrong group (DCT vs. No DCT). In case the use of DCT for a cow was not recorded, for example, these cows were included in the group without DCT. This may have resulted in a falsely reduced probability for IMI for this 'no DCT'-group, because DCT should lower the IMI chance (Bradley and Green, 2001; Bhutto et al., 2011; Halasa et al., 2009).
Cows can also be in the wrong group based on the IMI. As described above the use of on-line SCC can lead to selecting the wrong cows with an IMI. Therefore there can be cows that incur an IMI in the group of cows without an IMI and vice versa.
From 72% of the milkings after dry period, the on-line SCC was measured. Only cows were selected with at least 33% milkings with an available on-line SCC. There is a chance that there are a small number of cows that incur an IMI, but are not detected with an IMI, because of the lower amount of available SCC and due to this are in the group without an IMI while they has to be in the group with an IMI.
When a cow was treated with antibiotics, the milk was separated by the AMS, so that no SCC measurement could be carried out, and no SCC data was available in these periods to detect an IMI, while there was an infection in this situation, when the antibiotics was applied because of mastitis. Due to this it is possible that an IMI could not be detected in a cow, and this cow is in the group without an IMI while she has to be in the group with an IMI. Probably this does not play a big role in this study, because these cows has probably an elevated SCC before treatment and are because of this already in the group of cows with an IMI.

The large variation can also be explained by the use of a teat sealant. The application of teat sealants at drying off reduces the incidence of IMI and clinical mastitis in the subsequent lactation. This reducing effect is the same for cows that in addition did or did not receive DCT (Rabiee and Lean, 2013; Laven and Lawrence, 2008; Newton et al., 2008). Bhutto et al. (2011) suggest that teat seal could have the same reducing effect as DCT. In this study no complete data was available about the use of teat sealant and therefore no distinction was made between cows on the use of teat sealants, so in both groups (with and without DCT) are cows that did and did not receive a teat sealant.
The large variation can also be explained by the variation of the severity of IMI's. In the groups of primiparous and multiparous cows with an IMI are cows with clinical mastitis and cows with only subclinical mastitis. Also my research did not take into account the number of different IMI's during

the period after dry period. Possibly there is a relationship between the severity or number of IMI's after dry period and the on-line SCC before dry period.
The large variation between cows within a group (with or without DCT and with or without an IMI) could also be caused by the variation in available on-line SCC measurement per cow. From 68% of the milkings before drying off the on-line SCC was available. For multiparous cows, the highest correlation existed between the average on-line SCC during one month before the dry period and the occurrence of an IMI. But the amount of on-line SCC measurement that these averages were based on differs per cow. So for a cow with less on-line SCC measurements a single SCC measurement has a higher influence on the average than in a cow with more on-line SCC measurements.
For primiparous cows, the highest correlation existed between the number of on-line SCC measurement >500,000 cells/ml during the last week before dry period and the occurrence of an IMI. But this explanatory variable is highly influenced by the number of milkings with actual online SCC measurements. A primiparous cow with a few measurements probably should have a lower number of milkings with an on-line SCC > 500,000 cells/ml compared when it should have more on-line SCC measurements during this week before drying off.

4.3 Linear programming model

The LP model distributes the antibiotics at drying off over the different subgroups, with the goal to minimize the total costs related to administering DCT and total costs related to mastitis during the first month of the subsequent lactation. For every subgroup it compares the costs of mastitis after dry period based on the costs of mastitis and the probability of mastitis for the different activities of apply and do not apply DCT. If applying DCT lowers the costs of mastitis more than the costs of applying DCT are, it is economically profitable to apply DCT to this subgroup. When it is in more cows profitable to apply DCT than the restriction in total antibiotic use permits, the LP models distributes the antibiotics to these cows were DCT is the most profitable.
In subgroup 4, 5, 6, 8 and 10 the probability of an IMI is higher in the situation of applying DCT. That DCT does not reduce the probability of an IMI contradicts to the expectation. Bradley and Green (2001), Bhutto et al. (2011) and Halasa et al. (2009) mention that applying DCT reduces the occurrence of clinical mastitis in the dry period and during early lactation.
The directive of the professional organization of veterinarians in the Netherlands (KNMvD) and the Dutch Animal Health service is to apply antibiotics at drying off only in those cases when diagnostic research shows that the cow has an IMI. This means that antibiotics will be applied only curative at drying off. By default, the diagnosis of an IMI is based on SCC (KNMvD, 2013). Udders with a higher SCC are expected to be less healthy (Ruegg and Pantoja, 2013). In case this assumption is true, expected is that when in subgroups 3 and 9 DCT is profitable, it should be the same for subgroups 4, 5, 6, 10 and 11, which have a higher average SCC during the last month before drying off or a higher amount of milkings that exceeded the threshold of >500,000 cells/ml during the last week before drying off. A reason could be that the cows in these subgroups are more sensitive for getting an IMI and that even DCT does not lower this. It is possible that the occurrence of an IMI is more influenced by cow characteristics than DCT. Scherpenzeel et al. (2014) used a split-udder-design to determine the influence of DCT on the occurrence of mastitis. In this design, the cow's own influence stays the same and a better comparison can be made of the influence of DCT.
A more likely explanation is that the IMI probabilities in these subgroups are based on too few observations which make them unreliable. The most extreme examples of the large influence of a low number of observations are in subgroup 9 and 10. The occurrence of an IMI in subgroups 9 and 10 for primiparous cows that did not receive DCT are both based on one observation, which make this in subgroup 9 an IMI occurrence of 100% and in subgroup 10 an IMI occurrence of 0% when applying DCT. The outcomes of the LP model for these subgroups are entirely based on these two observations.

The LP model has a result of 1.6 DDDA on average per cow total antibiotic use, which is less than the restriction of 2.2 DDDA on average per cow. This is because the large number of subgroups where applying DCT is not economically profitable.
There are a couple of assumptions made for the input of the LP model. First the costs of mastitis is set at €235, while these costs vary between €164 (Hogeveen et al., 2011; Huijps et al., 2008) and €485 (Heikkilä et al., 2012). When only the costs of clinical mastitis are chanced in the LP model, both of these values do not chance the output of the LP model. The costs of subclinical mastitis was set at €32 for primiparous cows and €61 for multiparous cows, while these varies between €16 (Halasa et al., 2008) and €102 (Halasa et al., 2007). When only the costs of subclinical mastitis are chanced in the LP model, both of these values do not chance the output of the LP model.
This study assumed a ratio of 40% clinical and 60% subclinical mastitis cases of the total IMI cases. Van den Borne et al. (2008) and Maas (2014) did both research on the occurrence of subclinical and clinical mastitis. Based on the results of Van den Borne et al. (2008) they found a ratio of 20% clinical mastitis cases of total mastitis cases in primiparous cows and 26% in multiparous cows. Based on the results of Maas (2014) he found a ratio of 52% clinical mastitis cases of total mastitis cases in primiparous cows and 49% in multiparous cows. This shows that there is a large variation in ratio. This is probably due to the definition of subclinical mastitis. Van den Borne et al. (2008) used a threshold for SCC >200,000 cells/ml, while Maas (2014) based subclinical mastitis on a positive bacteriological examination. When using the SCC to identify an IMI, also the threshold used has influence. Using a higher threshold to identify an IMI, the ratio between clinical mastitis and total IMI's is also higher. This study used the same ratio for all the subgroups, while it is more plausible that this ratio differs among different subgroups as in Maas (2014).
Another assumption in this study is that no subclinical mastitis cases will be treated with antibiotics, while all clinical cases will be treated. It is also possible that cows with a severe clinical mastitis will be culled instead of treated with antibiotics. Assumed is that one mastitis treatment consists of 3 DDDA. It is possible that a treatment consists of more or less antibiotics, but 3 DDDA is an appropriate average to use in the LP model.
The model only takes into account the probability of an IMI during the first month after lactation. DCT has also influence on the IMI probability during the dry period and to a lesser extend also on the second and third month after dry period. When account is taken into these periods too, a more complete picture of the impact of DCT can be displayed.

This study uses an economic model instead of a bio-economic model. In this study no data about the cure rate of an existing IMI and next infection chance were used. Also no data were used about the infection pressure in the total herd due to an infected cow, which increases the IMI chance. These data were not available for this study. Applying these data and using a bio-economic model could possibly give more accurate results. Obtaining reliable results about this data needs more research and is time-consuming, while this does not mean that a bio-economic model leads to a different result concerning the selection criteria of applying SDCT.

4.4 Comparing dry off results using on-line SCC and LP criteria or milk recording test day SCC and KNMvD criteria

According to the directives of the KNMvD using the last milk recording test day, more cows are dried off than according to the result of the LP model based on on-line SCC. The group of cows that is dried off based on last milk recording test day and not when based on on-line SCC is bigger than the group of cows that is dried off based on on-line SCC and not when based on last milk recording test day. The group of cows that is dried off using the last milk recording test day and not according to on-line SCC (30.4%) is likely to exist for a high proportion of cows from group 4, 5, 6, 10 and 11. These are the groups that have a quite high average SCC before drying off or a high amount of milkings that exceeded the threshold >500,000 cells/ml and are not dried according to the LP result.

In 63.1% of the cows, the farmers made the same decision about drying off as the directives of the KNMvD based on the last MPR. This means that still 36.9% of the cows are not dried off according to the directives of the KNMvD based on the last MPR.
It was not possible to calculate the economic value of on-line SCC monitoring from an AMS relative to four to six weekly MPR. Based on the LP model, the total average costs of clinical and subclinical mastitis during the first month after dry period and drying off is available when SDCT is applied based on the on-line SCC. When SDCT is applied according to the last MPR, no costs of clinical and subclinical mastitis during the first month after dry period are available. The cows in this study were not exactly dried off according to the directives of the KNMvD, so the IMI probability and the associated costs of incurred clinical and subclinical mastitis during the first month after dry period could not be determined when the cows were dried off based on the last MPR.

4.5 Recommendations

To improve this study, more cows are needed to determine the correlation between different explanatory variables before drying off and the occurrence of an IMI in the subsequent lactation. To be more specific, more cows are needed with a low SCC before drying off. This prevents results of the different subgroups about the probability of an IMI when applying or not applying DCT to be based on a very small number of cows, and will make the results more reliable.
It is also advisable do determine the correlation between explanatory variable and IMI's separately for subclinical and clinical mastitis separately instead of total IMI's. Probably the variation in cows will be lower when groups with subclinical and clinical mastitis will be separated. This leads to higher correlations. Probably also DCT will have another effect on the probability of subclinical and clinical mastitis. Besides this, also in the linear programming model, separating clinical and subclinical mastitis will give a more accurate result on the total costs of mastitis, because the costs of clinical and subclinical mastitis differs significantly from each other.
To have more reliable results about the occurrence of an IMI, a bacteriological examination is more appropriate than a definition of an IMI based on increased SCC (Pyörälä, 2003; Schukken et al., 2003).
To determine the effect of DCT a split udder design is more suitable to avoid the interference of cow specific characteristics, defence against pathogens, construction of the udder and the teats and keratin production in the teat canal.
To avoid that the amount of available SCC measurements have an influence on the explanatory variable which count the amount of milkings with an SCC that exceeded the threshold of >500,000 cells/ml, it is possible to use a explanatory variable that counts the amount of milkings that exceeded a threshold in SCC as a percentage of the total available milkings with an SCC measurement.
It is important to take into account the use of teat seal. This has probably a disruptive effect on the correlation between explanatory variables and the occurrence of an IMI. The use of an IMI could also be used as an alternative or an addition to antibiotics in the LP model.
This study only used the SCC before drying off, separated for primiparous and multiparous cows, to predict the occurrence of an IMI in the subsequent lactation and to base on SDCT. Using an AMS, much more data of the individual cows are available, which will make the prediction of an IMI in the subsequent lactation more accurate. Different factors before drying off have influence on the occurrence of mastitis in the subsequent lactation. Next to SCC, Gundelachl et al. (2011) mentioned that age of the cow and Pinedo et al. (2012) mentioned that intermediate lactation length has influence on clinical mastitis and IMI in the subsequent lactation. Also milk yield before drying off has influence on the IMI occurrence in the subsequent lactation (Pinedo et al., 2012; Newman et al., 2010). Possibly, also the length of the dry period has influence on the IMI occurrence in the subsequent lactation as mention in Sawa et al. (2015), while Laven et al. (2014) and Steeneveld et al. (2013) mentioned no effect of dry period length on clinical mastitis in the subsequent lactation. Also conductivity on quarter level could probably have a predictive value in predicting the occurrence of an IMI in the subsequent lactation.

5 Conclusion

This study did not show a significant correlation between different explanatory variables based on the on-line SCC before drying off and the occurrence of an IMI during the first month of the subsequent lactation. This means that on-line SCC before drying off cannot (yet) predict the occurrence of an IMI in the subsequent lactation.

The prophylactic effect of DCT could not be established for all subgroups of cows, whereby no reliable selection criteria could be established based on on-line SCC before drying off. This means that selection criteria using on-line SCC monitoring has not (yet) benefits over selection criteria using MPR.

Because lack of required data, the economic value of on-line SCC measurement over MPR could not be determined.

More research is needed to predict the occurrence of an IMI in subsequent lactation to determine the best selection criteria for SDCT using data from an AMS, including on-line SCC.

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References

Autoriteit-Diergeneesmiddelen. (2014). *Het gebruik van antibiotica bij landbouwhuisdieren in 2013*

Berry, E. a, & Hillerton, J. E. (2002). The effect of selective dry cow treatment on new intramammary infections. *Journal of Dairy Science*, *85*(1), 112–21. doi:10.3168/jds.S0022-0302(02)74059-9

Bhutto, a. L., Murray, R. D., & Woldehiwet, Z. (2011). The effect of dry cow therapy and internal teat-sealant on intra-mammary infections during subsequent lactation. *Research in Veterinary Science*, *90*(2), 316–320. doi:10.1016/j.rvsc.2010.06.006

Bradley, a J., & Green, M. J. (2000). A study of the incidence and significance of intramammary enterobacterial infections acquired during the dry period. *Journal of Dairy Science*, *83*(9), 1957–65. doi:10.3168/jds.S0022-0302(00)75072-7

Bradley, a J., & Green, M. J. (2001). An investigation of the impact of intramammary antibiotic dry cow therapy on clinical coliform mastitis. *Journal of Dairy Science*, *84*(7), 1632–9. doi:10.3168/jds.S0022-0302(01)74598-5

Djabri, B., Bareille, N., Beaudeau, F., & Seegers, H. (2002). Quarter milk somatic cell count in infected dairy cows: a meta-analysis. *Veterinary Research*, *33*(4), 335–357. doi:10.1051/vetres

Green, L. E., Schukken, Y. H., & Green, M. J. (2006). On distinguishing cause and consequence: Do high somatic cell counts lead to lower milk yield or does high milk yield lead to lower somatic cell count? *Preventive Veterinary Medicine*, *76*(1-2), 74–89. doi:10.1016/j.prevetmed.2006.04.012

Gundelachl, Y., Kalscheuerl, E., Hamann, H., & Hoedemakerl, M. (2011). Risk factors associated with bacteriological cure , new infection , and incidence of clinical mastitis after dry cow therapy with three different antibiotics. *Journal of Veterinary Science*, *12*(3), 227–233.

Halasa, T., Huijps, K., Østerås, O., & Hogeveen, H. (2007). Economic effects of bovine mastitis and mastitis management: a review. *The Veterinary Quarterly*, *29*(1), 18–31. doi:10.1080/01652176.2007.9695224

Halasa, T., Nielen, M., De Roos, a P. W., Van Hoorne, R., de Jong, G., Lam, T. J. G. M., Van Werven, T. & Hogeveen, H. (2009). Production loss due to new subclinical mastitis in Dutch dairy cows estimated with a test-day model. *Journal of Dairy Science*, *92*(2), 599–606. doi:10.3168/jds.2008-1564

Halasa, T., Nielen, M., & Hogeveen, H. (2008). Economic loss due to milk yield loss caused by new subclinical mastitis cases estimated using a test-day model. *Mastitis Control - From Science to Practice*, 443.

Halasa, T., Nielen, M., van Werven, T., & Hogeveen, H. (2010). A simulation model to calculate costs and benefits of dry period interventions in dairy cattle. *Livestock Science*, *129*(1-3), 80–87. doi:10.1016/j.livsci.2010.01.009

Halasa, T., Osterås, O., Hogeveen, H., van Werven, T., & Nielen, M. (2009). Meta-analysis of dry cow management for dairy cattle. Part 1. Protection against new intramammary infections. *Journal of Dairy Science*, *92*(7), 3134–49. doi:10.3168/jds.2008-1740

Heikkilä, A. M., Nousiainen, J. I., & Pyörälä, S. (2012). Costs of clinical mastitis with special reference to premature culling. *Journal of Dairy Science*, *95*(1), 139–50. doi:10.3168/jds.2011-4321

Hogeveen, H., Huijps, K., & Lam, T. J. G. M. (2011). Economic aspects of mastitis: new developments. *New Zealand Veterinary Journal*, *59*(1), 16–23. doi:10.1080/00480169.2011.547165

Huijps, K., & Hogeveen, H. (2007). Stochastic modeling to determine the economic effects of blanket, selective, and no dry cow therapy. *Journal of Dairy Science*, *90*(3), 1225–34. doi:10.3168/jds.S0022-0302(07)71611-9

Huijps, K., Lam, T. J., & Hogeveen, H. (2008). Costs of mastitis: facts and perception. *The Journal of Dairy Research*, *75*(1), 113–20. doi:10.1017/S0022029907002932

Kamal, R. M., Bayoumi, M. A., & Abd El Aal, S. F. A. (2014). Correlation between some direct and indirect tests for screen detection of subclinical mastitis, *21*(3), 1213–1218.

KNMvD. (2013). *Richtlijn Antimicrobiële middelen bij het droogzetten van melkkoeien* (pp. 1–41).

Laven, R. A., Balcomb, C. C., Tulley, W. T., & Lawrence, K. E. (2014). Effect of dry period length on the effect of an intramammary teat sealant on the risk of mastitis in cattle treated with antibiotics at drying off. *New Zealand Veterinary Journal*, *62*(4), 214–20. doi:10.1080/00480169.2013.879689

Laven, R. A., & Lawrence, K. E. (2008). Efficacy of blanket treatment of cows and heifers with an internal teat sealant in reducing the risk of mastitis in dairy cattle calving on pasture. *New Zealand Veterinary Journal*, *56*(February 2015), 171–175. doi:10.1080/00480169.2008.36830

Maas, L. (2014). Selective Dry Cow Therapy : the effect of different selection criteria on costs , antibiotic use and mastitis infections at Dutch dairy farms.

Newman, K. a, Rajala-Schultz, P. J., Degraves, F. J., & Lakritz, J. (2010). Association of milk yield and infection status at dry-off with intramammary infections at subsequent calving. *The Journal of Dairy Research*, *77*(1), 99–106. doi:10.1017/S0022029909990380

Newton, H. T., Green, M. J., Benchaoui, H., Cracknell, V., Rowan, T., & Bradley, a J. (2008). Comparison of the efficacy of cloxacillin alone and cloxacillin combined with an internal teat sealant for dry-cow therapy. *The Veterinary Record*, *162*, 678–684. doi:10.1136/vr.162.21.678

Owens, W. E., Nickerson, S. C., Boddie, R. L., Tomita, G. M., & Ray, C. H. (2001). Prevalence of mastitis in dairy heifers and effectiveness of antibiotic therapy. *Journal of Dairy Science*, *84*(4), 814–817. doi:10.3168/jds.S0022-0302(01)74538-9

Pinedo, P. J., Fleming, C., & Risco, C. a. (2012). Events occurring during the previous lactation, the dry period, and peripartum as risk factors for early lactation mastitis in cows receiving 2 different intramammary dry cow therapies. *Journal of Dairy Science*, *95*(12), 7015–26. doi:10.3168/jds.2012-5398

Pyörälä, S. (2003). Review article Indicators of inflammation in the diagnosis of mastitis. *Veterinary Research*, *34*, 565–578. doi:10.1051

Rabiee, A. R., & Lean, I. J. (2013). The effect of internal teat sealant products (Teatseal and Orbeseal) on intramammary infection, clinical mastitis, and somatic cell counts in lactating dairy cows: a meta-analysis. *Journal of Dairy Science*, *96*(11), 6915–31. doi:10.3168/jds.2013-6544

Ruegg, P. L., & Pantoja, J. C. F. (2013). Understanding and using somatic cell counts to improve milk quality. *Irish Journal of Agricultural and Food Research*, *52*, 101–117.

Sampimon, O., Barkema, H. W., Berends, I., Sol, J., & Lam, T. (2009). Prevalence of intramammary infection in Dutch dairy herds. *The Journal of Dairy Research*, *76*(2), 129–36. doi:10.1017/S0022029908003762

Sampimon, O. C., Riekerink, R. G. M. O., & Lam, T. J. G. M. (2008). Prevalence of subclinical mastitis pathogens and adoption of udder health management practices on Dutch dairy farms : preliminary results. *Mastitis Control - From Science to Practice*, 39–46.

Sampimon, O., van den Borne, B. H., Santman-Berends, I., Barkema, H. W., & Lam, T. (2010). Effect of coagulase-negative staphylococci on somatic cell count in Dutch dairy herds. *The Journal of Dairy Research*, *77*(3), 318–24. doi:10.1017/S0022029910000191

Santman-Berends, I. M. G. A., Olde Riekerink, R. G. M., Sampimon, O. C., van Schaik, G., & Lam, T. J. G. M. (2012). Incidence of subclinical mastitis in Dutch dairy heifers in the first 100 days in lactation and associated risk factors. *Journal of Dairy Science*, *95*(5), 2476–84. doi:10.3168/jds.2011-4766

Sawa, A., Krężel-Czopek, S., & Bogucki, M. (2015). Dry Period Length as Related to Milk Yield and SCC During the First Month of Subsequent Lactation. *Annals of Animal Science*, *15*(1), 155–163. doi:10.2478/aoas-2014-0051

Scherpenzeel, C. G. M., den Uijl, I. E. M., van Schaik, G., Olde Riekerink, R. G. M., Keurentjes, J. M., & Lam, T. J. G. M. (2014). Evaluation of the use of dry cow antibiotics in low somatic cell count cows. *Journal of Dairy Science*, *97*(6), 3606–14. doi:10.3168/jds.2013-7655

Schukken, Y. H., Wilson, D. J., Welcome, F., Garrison-Tikofsky, L., & Gonzalez, R. (2003). Review article Monitoring udder health and milk quality using somatic cell counts, *34*, 579–596. doi:10.1051/vetres

Sharma, N., Singh, N. K., & Bhadwal, M. S. (2011). Relationship of Somatic Cell Count and Mastitis: An Overview. *Asian-Australasian Journal of Animal Sciences*, *24*(3), 429–438. doi:10.5713/ajas.2011.10233

Steeneveld, W., Schukken, Y. H., van Knegsel, a T. M., & Hogeveen, H. (2013). Effect of different dry period lengths on milk production and somatic cell count in subsequent lactations in commercial Dutch dairy herds. *Journal of Dairy Science*, *96*(5), 2988–3001. doi:10.3168/jds.2012-6297

Van den Borne, B. H. P., Van Schaik, G., Lam, T. J. G. M., & Nielen, M. (2008). A comparison of the occurrence of mastitis in Dutch primi- and multiparous cows. *Mastitis Control - From Science to Practice*, 55–62.