A throughout evaluation of the Lely Astronaut automatic milking system's health report

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Abstract

In 2016, Lely introduced a health report; an extension of the earlier udder health report that was part of the management system (Time for Cows, T4C). The health report enables the farmer to be able to detect more diseases than just mastitis with the Lely Astronaut. The overall goal of this study is to evaluate the performance of the health report from the management system T4C from the Lely Astronaut. To get this insight, the positive and negative predictive value has been calculated, the number of false positives has been determined and the use of the health report by farmers has been examined. Six farms around Utrecht that use a Lely Astronaut were visited three to four times for the study. During the first visit, a questionnaire was taken to get an impression of the farm. Each visit the farmer was interviewed about the attentions on the health report that day. After this interview, the student examined the cows that were on the health report that day with the aid of two flowcharts. The student also visually assessed with the aid of a flowchart the health of five cows randomly selected per AMS that were not on the health report. A total of 41 attentions were examined on the health reports. In this study, a value of 90% was found for the positive predictive value and a value of 89% was found for the negative predictive value. Furthermore, a percentage of 10% false positives has been found. Farmers checked once a week to three times a day the health report and it appeared that on average 56% of all attentions are checked by the farmers. The most important reason to check a cow on the report is when the attention for increased conductivity or mastitis attention is on the report. It can be concluded that the health report of T4C van Lely has been improved compared to the udder health report of T4C. The positive predictive value has increased compared to previous findings and farmers are checking more attentions than before. However, cows are still missing on the report and for this reason the report is mainly used for the detection of mastitis. It is a challenge for Lely to improve the detection models drawn wider than mastitis with the aim of missing fewer cows on the health report.

Keywords: (sub)clinical mastitis, metritis, ketosis, lameness, automatic milking, detection, T4C, health report

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1. Introduction

Since the introduction of automatic milking systems (AMS) in 1992 (Hogeveen et al., 2010), the number of farms that milk their cows with AMS has increased considerably. In 2018, there are 3,959 of the 17,667 dairy farms in the Netherlands that use an AMS (KOM, 2018). This means that almost 25% of all dairy farms in the Netherlands have an AMS. The major reasons for the increasing choice for AMS are reduced labor requirements as well as more flexible working hours and economic benefits (Jacobs and Siegford, 2012). Furthermore, AMS reduces the labor costs and gives dairy farmers the opportunity to manage larger herds (Rutten et al., 2013).

However, the choice for an AMS does ensure a change in working methods for the farmer. For example, during milking with an AMS there is no milker nearby to be able to detect diseases such as mastitis (Kamphuis et al., 2010). For this reason, the farmer also needs other sources of information to stay up-to-date on the udder health of his cows. AMS therefore contains sensors that collect different types of udder health information from the cow. The sensors in the AMS measure the somatic cell count, electrical conductivity, milk color, milk yield and milk temperature to detect clinical mastitis (Hogeveen et al., 2010). Until 2016 the Lely Astronaut AMS only produced an udder health report, based on the mentioned udder health sensors, which lists the cows that are suspected of mastitis.

However, technology is developing and in recent years new sensors have been added to the AMS. For example, there are now sensors that measure the rumination time, activity, eating minutes, residual food and the weight of the cow. These new sources of information increase detection possibilities. Cows with ketosis or metritis show a reduced milk yield, rumination time and activity (Steensels et al., 2016). Furthermore, it has also been found that a cow with a post-calving disease (e.g. ketosis and metritis) visits the AMS less often, shows a decrease in body weight and a lowered milk trend. Therefore, with the aid of the new sensors, post-calving diseases can now also be detected with an AMS. In addition, the new sensors can also be used to detect lameness (King & DeVries, 2018), by measuring activity with pedometers and activity meters (Rutten et al., 2013). In 2016, Lely introduced a health report; an extension of the earlier udder health report that is part of the management system (Time for Cows, T4C). The health report enables the farmer to be able to detect more diseases than just mastitis with the Lely AMS. The report combines all sensor data and calculates the disease probability per individual cow on basis of these data, which provides a number between 10 and 100. The cows that eventually appear on the report need extra attention from the farmer. The higher the disease probability, the higher the chance that the cow is ill. In this way, the farmer can detect a disease early. An early and adequate treatment improves the recovery process and can prevent diseases in other cows (Steensels et al., 2016).

Several studies show that the clinical mastitis detection models, such as the udder health report, still have a large number of false positive attentions (Hogeveen et al., 2010; Buma, 2012, Steeneveld et al., 2010). It is still unknown to what extent the new algorithms and Lely's new health report have reduced this number of false positive attentions and thus what the detection performance is. This is important so that farmers as well as veterinarians know how reliable and valid the results from the health report are. Also, this will improve the quality of the veterinarian's advice to the farmer in terms of treatment and management. A notable finding was that farmers not always check all the cows on the udder health report (Buma, 2012; Van der Vorst and Ouweltjes, 2003). Therefore, it is interesting as well to investigate how farmers use the new health report.

Research goal

The overall goal of this study is to evaluate the performance of the health report from the management system T4C from the Lely Astronaut. To get this insight, the following research questions are formulated:

- Which percentage of cows on the health report is checked by the farmer?
- How often does the farmer look at the health report?
- From which disease probability onwards does the farmer check the cows on the health report?
- Do farmers miss cows on the health report?
- What is the positive predictive value of the health report?
- What is the number of false positive attentions on the health report?
- What is the negative predictive value of the health report?

2. Material and methods

2.1 Development of the flow charts

In collaboration with an expert from the Faculty of Veterinary Medicine in Utrecht, two flow charts have been developed for examining the cows on the health report. The flow charts have been developed for assessing a cow as sick or not sick. Figure 1 shows the flow chart used to examine (sub)clinical mastitis, metritis, ketosis and lameness.

During the farm visits, the health report was viewed first. In the event that an attention was given for a specific quarter, a milk sample was taken from that quarter. Before the udder was touched, disposable gloves were put on (Kandeel, 2019). The udder was cleaned with an udder cloth and 20-mL milk samples were collected after discarding the first 3 squirts. The milk was visually assessed for clots, color and consistency. The udder was checked for hardness, swelling, color and painfulness. The samples were taken to the laboratory of the Faculty of Veterinary Medicine in Utrecht. The somatic cell count (SCC) was determined using the DeLaval cell counter. Clinical mastitis was defined as abnormal milk and/or udder, with an SCC higher than 200,000 cells/mL (Petzer et al., 2017). Subclinical mastitis was defined as no abnormal milk and/or udder, with an SCC of more than 200,000 cells/mL (Bach et al., 2019).

If there was no attention for a specific quarter on the health report, a vaginal toucher was done to test cows for metritis. Disposable gloves were put on and vaginal discharge was assessed by inserting into the vaginal canal up to the cervix and taking a sample of the discharge (Neave et al., 2018). The discharge was assessed for odor, color and consistency. Cows were classified as having metritis when smelly, red-brown, serous discharge was observed and/or afterbirth was still present.

If cows were not classified as having metritis and were in the first 6 weeks of lactation, a ketosis blood test was performed (Enjalbert et al., 2001). With the help of the Precision Xceed (Abbott Diabetes Care) the concentration of β-hydroxybutyrate (BHB) in the blood can be measured. Cows were classified as having ketosis when the blood BHB concentration was higher than 1,200 μmol/L.

In order to be able to assess cows that did not have one of the above diseases as being sick, the overall impression of the cow was also assessed and the temperature was measured. The overall impression was visually observed using a developed flow chart (See Figure 2). The behaviour and level of consciousness were assessed by paying attention to the behaviour and the response to stimuli. A cow was classified as sick when the cow was drowsy and did not respond to stimuli. Posture and gait were assessed using a locomotive score card (See Appendix A1). A cow was classified as sick when the cow was assessed with a locomotive score of 3, 4 or 5. The nutritional status was determined using a body condition score card (See Appendix A2). A cow with a body condition score of 1 was classified as sick. The care condition was

assessed by means of the fur. If the fur was dull and not contiguous, the cow was classified as sick (Kuiper & Nieuwstadt, 2014). The manure was evaluated using a manure score card (See Appendix A3). A cow was classified as sick with a manure score of 1 or 2. Finally, a cow was assessed as sick if the temperature was measured above 39 degrees (Kuiper & Nieuwstadt, 2014).

2.2 Data collection

Data was collected from 26 February to 22 March, six farms around Utrecht that use a Lely Astronaut were selected for the study. Of the six farms, three were selected by the Universitaire Landbouwhuisdieren Praktijk (ULP) and three were selected by Lely Industries N.V. The farms were visited three to four times.

During the first visit, a questionnaire was taken to get an impression of the farm and to gain insight into the degree of satisfaction of the AMS. The questionnaire is added in Appendix B. After this questionnaire, the student and the farmer reviewed the health report. Each visit a small interview followed about how he used the health report and about the cows on the health report. An example of this interview is added in Appendix C. After this interview, the student examined the cows that were on the health report that day. The student assessed the overall impression with the aid of flowchart 2 (See Figure 2), recorded the temperature of the cows and checked the cows on the report for mastitis, ketosis and metritis with the aid of flowchart 1 (See Figure 1).

The findings were noted on a registration form. Attentions from cows that were in heat were excluded. The student also visually assessed the health of five cows randomly selected per AMS that were not on the health report. The cows were assessed as healthy or sick. This visual assessment was made by using flowchart 2.

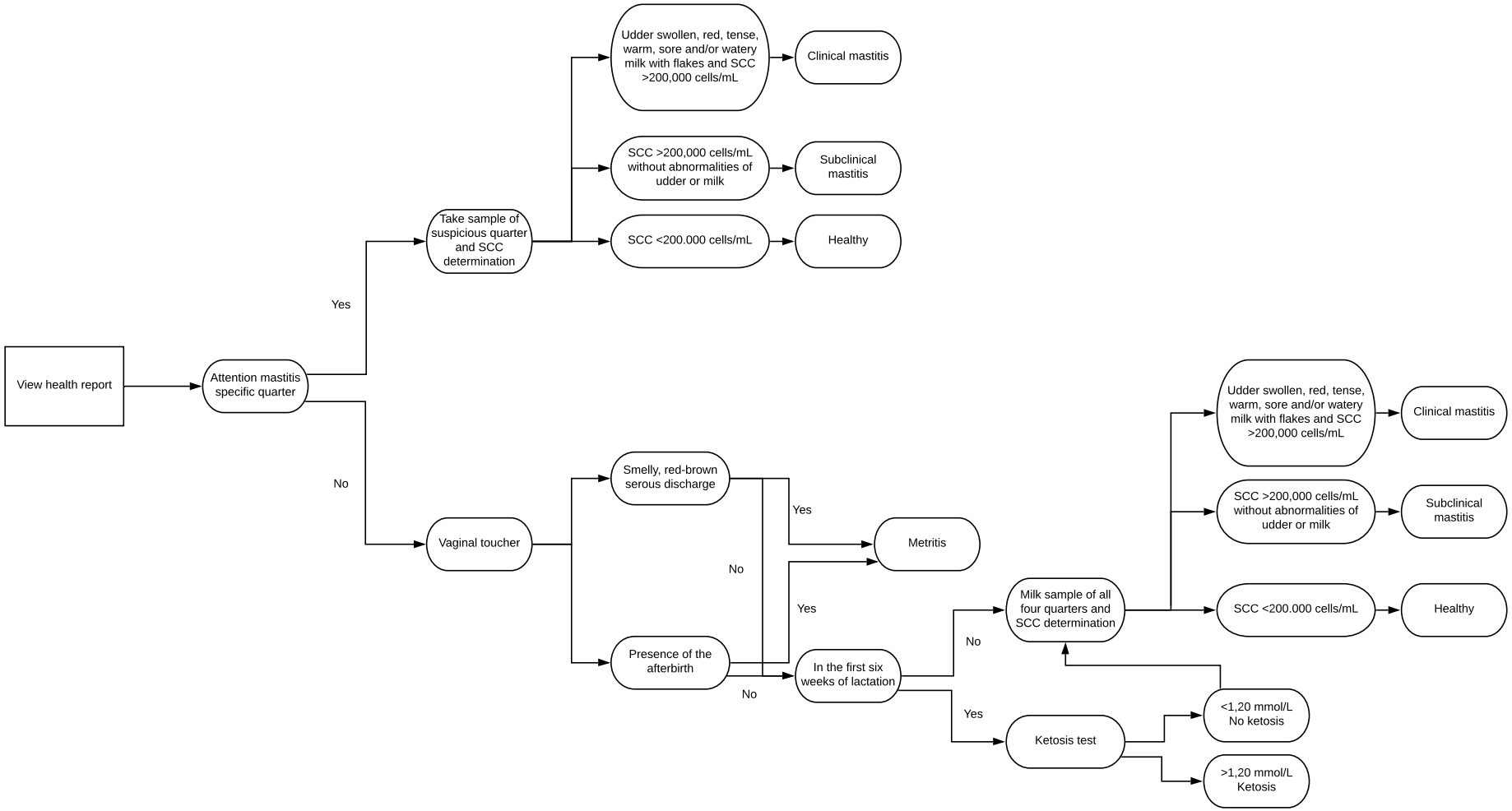


Figure 1. Flow chart for examining mastitis, metritis and ketosis of cows with an attention on the T4C health report

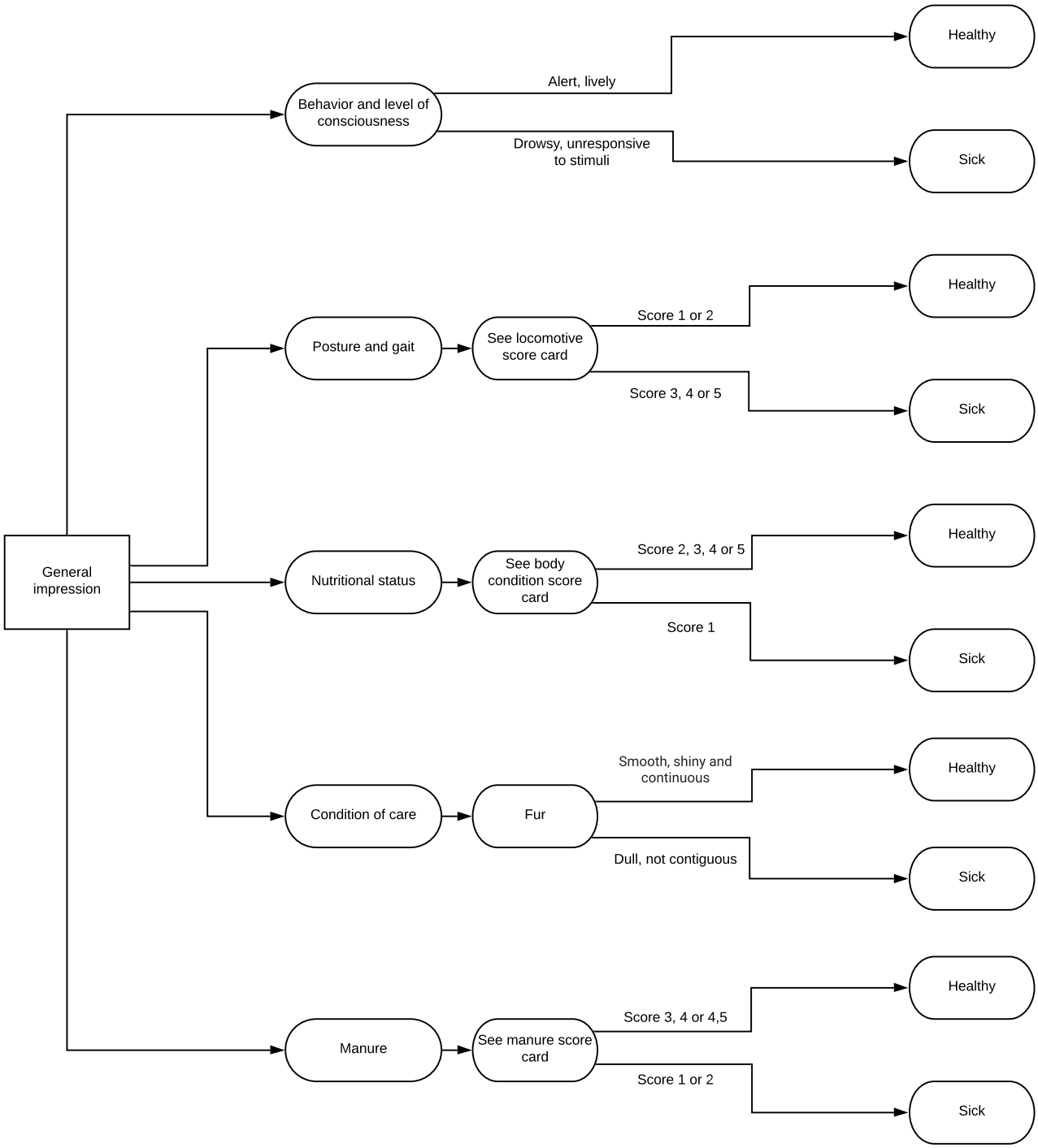


Figure 2 . Flow chart for assessing the overall impression of cows

2.3 Data recording

The findings of the flow charts of the assessed and examined cows were processed in an excel database. This was done separately for each farm. The cow number, disease score, number of days in lactation and the details of the attentions (conductivity, milk production deviation, fat/protein ratio, temperature, activity, residual food) on the health report were also added for each attention. It was noted whether the attention cows had been checked by the farmer and why this had happened or not.

A total of 41 cows that were on a health reports were examined. An overview was made of the number of attentions per farm and the assessments of each cow were divided between sick or not sick. A table was also made with an overview of the randomly selected cows that were not on the health report. These attentions were split between sick or not sick. Finally, a table has been added in which the reasons of the farmers for checking the cows or not checking the cows on the health report are shown.

2.4 Data analysis

To analyze the data, the positive predictive value and the negative predictive value of the health report were calculated. This was done separately for each farm, but a total value was also calculated for the results of all farms combined. In addition, the number of false positives and number of false negatives were calculated. This was calculated per farm, but as well in total with all farms combined.

The following formulas were used:

Positive predictive value = TruePosCount / (TruePosCount + FalsePosCount)

TruePosCount = Number of observations where the cow is sick with an attention
FalsePosCount = Number of observations where the cow is healthy with an attention

Negative predictive value = TrueNegCount / (TrueNegCount + FalseNegCount)

TrueNegCount = Number of observations where the cow is healthy without an attention
FalseNegCount = Number of observations where the cow is sick without an attention

3. Results

3.1 The selected farms

The herd size of the farms varied between 47 and 250, and the number of AMS varied between 1 and 4. Table 1 shows the specific characteristics of each farm.

Table 1. Characteristics of the farms

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
# Cows	47	100	250	221	100	100
# AMS	1	2	4	3	2	2
Year of installation AMS	2011	2014	First 2 in 2015 Second 2 in 2017	2013	2015	2013
AMS type	A4	A4	A4	A4	A4	A4
# Cows/AMS	47	50	63	74	50	50
Milk production (Kg/305 days)	11,000	9,000	11,500	9,485	8,550	11,000
Mean SCC 2018 (*1,000 cells/mL)	90	150	80	150	180	200
Extra AMS sensor[1]	rumination	rumination	No	Activity	Eating minutes	Activity
Estimated treated clinical mastitis cases in 2018 (%)	0	20	15	5	6	10
Estimated treated cows with ketosis in 2018 (%)	17	10	5	2	10	1
Estimated treated cows metritis in 2018 (%)	0	2	5	2	1	0
Estimated treated lame cows in 2018 (%)	17	20	10	9	2	10

[1]standard sensors are electrical conductivity, temperature, color, fat / protein ratio, milk production deviation

Table 2 shows the most important prefixes of the farms. The table shows that the number of times the farmer checked the report varied from once a week to three times a day and the percentage of cows on the health report per day varied from 1% to 2%.

Table 2. AMS prefixes of the farms noted from T4C during the first visit

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
Average milkings/cow/day	3,2	3,2	3,1	2,6	2,6	3,3
Average percentage of cows on the health report/day (%)	2	2	2	1	2	1
Average number of failure milkings/day/cow	1,6	3,6	5	4,5	5,9	1,5
Average number of refused milkings/day/cow	1,3	7,1	3,6	1,9	9,2	6,6
Number of times the report is checked each day	3	2	3	3	1	Once a week

3.2 Checked attentions by farmers

Of the 41 attentions on the health reports, 23 were checked by the farmer and 18 attentions on the health report were not checked by the farmer. A more detailed overview of this per farmer is shown in table 3.

Table 3. Overview of the number of attentions checked by the farmer during the farm visit days

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Total	Percentage (%)
Number of attentions checked (n)	3	6	4	6	4	0	23	56
Number of attentions not checked (n)	1	2	4	4	5	2	18	44

Table 4 shows an overview of the reasons why a farmer checked the attentions on the health report. Results showed that 26% of the checked attentions was checked because there was an attention on the health report for increased conductivity, and 22% were checked because these cows had already been treated by the farmer and were now under control. Another 13% was checked because the cows received an attention for mastitis on the health report.

Table 4. Overview of farmer's criteria to check a cow with an attention

Criteria	Number of attentions (n)	Percentage attentions (%)
Attention increased conductivity	6	26
Already treated cow, is being checked	5	22
Mastitis attention	3	13
Fresh cow, difficult start	2	9
Large milk production decline	2	9
Treat lameness	2	9
Fat / protein ratio and temperature deviation alarming	1	4
Repeated attention	1	4
Fresh cow with caesarean section, is being checked	1	4

Table 5 shows the reasons why a farmer would not check the cows with an attention on the health report. It can be seen that 22% of the cows are not checked because the farmer does not find the milk production deviation alarming and 17% is not checked because the cow still often comes to the AMS. Another 17% is not checked because the farmer already knows the reason why the cow is on the health report.

Table 5. Overview of farmer's criteria not to check a cow with an attention

Criteria	Number of attentions (n)	Percentage attentions (%)
Milk production deviation not alarming	4	22
Still often comes to the AMS	3	17
Farmer knows the cause	3	17
Conductivity attention not alarming	2	11
Milk production normal	2	11
Almost in dry off group	1	6
Fresh cow with mastitis attention	1	6
Repeated attention	1	6
Chronic high conductivity	1	6

None of the farmers checked a cow on the health report from a certain limit value of the disease probability. The disease probability was not used or was used in combination with the specific attentions. A more detailed description per farmer can be found in Appendix D table 1.

Four out of six farmers sometimes missed cows on the health report. Two of these farmers missed cows with ketosis on the health report. An overview of the experience of all farmers about missing cows on the health report is presented in table 6.

Table 6. Overview of the experiences of farmers about missing cows on the health report

Farmer	Missing cows on the health report
1	No
2	Yes
3	No
4	Yes, some cows sometimes have a high production decrease but are not on the report.
5	Yes, cows with ketosis and rumen acidification
6	Yes, cows with ketosis

3.3 Attentions of the health report

In total, 41 attentions were on the health reports, and 37 attentions were assessed by the student to be sick and are therefore cows with a justified attention. A more detailed table can be found in Appendix E table 1, which contains the cow number, lactation days, disease score, findings of T4C and the findings from the student. Five attentions were assessed by the student as healthy, and these cows are thus incorrectly mentioned on the health report. Table 7 shows an overview of the attentions per farm, the positive predictive value and the percentage of false positives of all farms separately. It can also be seen that 90% of all attentions were justified, and 10% of the attentions were false positive. These were attentions from cows that the student had assessed as healthy.

Table 7. Overview of the percentages of the positive predictive value, the false positives per farm and the number of attentions per farm and the division of the attentions into sick and healthy

Farm	Attentions classified as sick (n)	Attentions classified as healthy (n)	Total attentions (n)	Positive predictive value (%)	False positives (%)
1	3	1	4	75	25
2	8	0	8	100	0
3	6	2	8	75	25
4	9	1	10	90	10
5	9	0	9	100	0
6	2	0	2	100	0
Total	37	4	41	90	10

Table 8 provides an overview of the assessment of the random selected cows that were not on the health report. Of the 215 cows that were visually assessed by the student, 191 cows were found to be healthy, but 24 cows were assessed by the student to be sick. A more detailed table can be found in Appendix F table 1, which contains the cow number and the findings from the student. Therefore, 89% of the cows randomly selected in the barns were assessed as healthy.

Table 8. Overview of the randomly assessed cows that were not on the health report

	Farm 1	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**	**Farm 6**	**Total**
# AMS (n)	1	2	4	3	2	2	14
# randomly assessed cows (n)	20	40	60	45	30	20	215
# cows assessed as sick (n)	3	3	1	6	10	1	24
# cows assessed as healthy (n)	17	37	59	39	20	19	191
Negative predictive value (%)	85	93	98	87	67	95	89

4. Discussion

4.1 Comparison with other studies

The purpose of this study was to evaluate the T4C Lely's health report. In this study it was found that farmers check the health report varying from once a week to three times a day. If the farmers looked at the report, the disease probability was not used or was used in combination with the specific attentions. It turned out that 56% of all attentions were checked by the farmer. It was found that 90% of the checked attentions were correct and that these cows were therefore correctly included on the health report. No other studies have been found in the scientific literature that also have examined Lely's health report. Van der Tol's (2016) proceedings paper did look at the potential of a new health report that made use of a Naïve Bayes Classification Technique using all farm sensor data available. But this paper used a different set up for registering sick cows, in which farmers registered the sick cows and subclinical cows were ignored. Therefore, comparison with this paper is difficult. However, Buma (2012) conducted a study on Lely's udder health report. The udder health report was the precursor of the health report, and therefore the results of the current study will be compared with the results of Buma (2012).

A milk production deviation that was not alarming for the farmer appears in the current study to be the most important reason to not check an attention on the health report. This result is in line with results of Buma (2012). Also, if the farmer knew the cause of the attention on the health report or when the cow still often came to the AMS, the attention often turned out not to be checked. The most important reason to check a cow on the report was when the attention for increased conductivity or mastitis attention was on the report. It appears that the health report is still mainly used for mastitis detection, as the old udder health report did.

This research showed that the positive predictive value between the farms varied between 75% and 100%, with an average of 90%. This means that 90% of all attentions on the health report were diagnosed as sick. Buma (2012) showed a variation of the positive predictive value between the farms from 23% to 56%. The degree of variation is therefore approximately the same, but the value of the positive predictive value has almost doubled. This may mean that the health report of today gives more reliable attentions than the udder health report evaluated in 2012. However, the fact that Buma (2012) made use of the udder health report must be taken into account, which means that only clinical and subclinical mastitis were considered.

A detection system for mastitis should have a sensitivity of 80% and a specificity of 99% (Hogeveen et al., 2010). The decision tree model based on ruminating, activity, milk yield, body weight and voluntary visits to the AMS for post-calving diseases, mentioned in the study by Steensels et al. (2016) gave an overall accuracy of 78% with a sensitivity of 69% and a specificity of 87%. The lameness detection model based on daily activity data, milk data and data from the computerized concentrate feeders in the study by De Mol et al. (2013) showed a sensitivity of 85.5% and specificity of 88.8%. The results of these studies combined show that the positive predictive value of 90% of the health report in the current study reasonably match previous findings and even show higher accuracy than previous findings. This 90% shows that the health report is useful for the management of farms. It depends on the farmer whether 10% false positive animals on the health report is an acceptable number. It differs per farmer how much time they want to put in the report and how much they are bothered by false positive animals. 0% false positive cows are practically impossible when it is taken into account that cows can also cure spontaneously.

In the past years a common complaint of farmers working with an AMS was the high number of false positive attentions (Kamphuis et al., 2008; Hogeveen et al., 2010). It seems that the number of false positive attentions has decreased. In the current study, only one farmer mentioned this as a problem. This can also be seen in the literature, previous studies found false

positive values of 18%, 60%, 27% while the current study found a value of 10% (Mottram et al., 2007; Buma, 2012; Cavero et al., 2007). This seems to be the reason why the motivation of farmers to check an attention seems to have increased. As mentioned, in the current study 56% of all attentions were checked by the farmer. This percentage is much higher when compared with the results of Buma (2012), who found 4% checked attentions.

In contrast to Buma (2012), the current research has also evaluated the cows not included on the health report. With this additional information, a calculation of the negative predictive value has been provided, which varied between farms between 67% and 96% with an average of 89%. This means that 89% of the randomly assessed cows that are not on the health report have been assessed as healthy. This result means that the majority of the sick cows will appear on the health report. But this also means that a small proportion of the cows that are sick will not appear on the health report, and these cows will be missed more quickly by the farmer or later noticed by the farmer. It is important that a farmer notice a sick cow as soon as possible because as mentioned before, an early and adequate treatment helps with a good recovery process and saves costs by preventing a further decrease in milk production and prevent diseases in other cows (Steensels et al., 2016).

4.2 Variation between farms

The variation in results between the farms could be explained by the difference in prevalence of the various diseases on the farms. The farmer-estimated prevalence of clinical mastitis, ketosis, metritis and lameness from 2018 were known (See table 1). However, the prevalence of the aforementioned diseases from 2019 were not known, therefore it was not possible to link the prevalences to the positive predictive value. In addition, the variation could also be explained by the possibility for farmers to adjust the standard settings of Lely's T4C. As a result, some farmers in the current study had lower threshold values for deviating values than others (See Appendix G table 1). A cow will appear on the health report faster with a lower threshold than when the standard settings are set. Furthermore, the data used in this study came from six different Dutch dairy farms. No distinction was made between factors on the farm such as the type of floor, type of freestalls, number of cows, numbers of milkings and level of overcrowding. These factors could all contribute to the degree of the prevalence of diseases and thus to the positive predictive value (Solano et al., 2015; Penry, 2018; Mbithi, 2008). Because no distinction has been made between all these factors, this could also be an explanation for variation between the farms. Finally, the fact that not all farmers had the same type of sensors can cause variation between the farms. Not all farms had a rumination or activity sensor, while these sensors are important for the detection of ketosis and lameness (Steensels et al., 2016, Rutten et al., 2013).

4.3 Limitations of the study

The results obtained by this study may be influenced by a few factors. First of all, the possible existence of metritis has been investigated by doing a vaginal touch as described in Neave et al. (2018). It is possible that with another method for detecting metritis, such as rectal examination or examination with a speculum as described in Kuiper et al. (2014), a different number of cows with metritis would be established. Secondly, the number of farms was too small to give a good reflection of reality. In order to get a better reflection of reality, more than six farms should participate in the research, so the total number of attentions on the health report will increase. Furthermore, the randomly selected cows that were not on the health report were only assessed visually. If these cows were assessed physically as well, the number of sickly assessed cows could be higher. Cows that were not visually identifiable as being sick will be missed by the researcher in this study. In addition, not all cows from the farm have been visually assessed. A random sample was taken of five cows per AMS. The results of the negative

predictive value would be more reliable if a future study incorporate the entire lactating herd. Finally, in the current study only cows were assessed by means of the flow charts and a cow was only assessed as sick or not sick. With these flow charts it was not possible to identify multiple diseases in a cow. Therefore, in a follow-up study it might be relevant to fully examine every cow that has an attention.

4.4 Future research

Future studies should incorporate data from the entire lactating herd. When all animals of the herd are fully and not partially visually examined, a better picture can be formed of which animals are missed and why these animals are missed by the health report. If this is better investigated, the farmer or Lely can take appropriate measures to increase the negative predictive value.

A lot of research has been done into mastitis detection models (e.g., Kamphuis et al., 2008; Mottram et al., 2007; Khatun et al., 2018). There are far fewer studies in the literature that have done research into detection models of other diseases (King & DeVries, 2018; Steensels et al., 2016). The current study shows that several farmers indicate that they missed cows with ketosis on the health report. There is thus a wish for improvement. For this reason, future studies should focus more on detection models drawn wider than mastitis with the aim of missing fewer cows on the health report.

More attention should also be paid to the possibilities of computer learning detection models. Connecterra is an example that makes the first steps towards artificial intelligence (Connecterra, 2019). Their goal is to make global agriculture more productive, humane and sustainable using sensors and machine learning. They have developed a program (ida) based on artificial intelligence. Ida can detect the behavior of cows with regard to health, fertility, nutrition and heat stress. It is a challenge for Lely to also look at the possibilities of detection models based on artificial intelligence.

5. Conclusions

The health report of T4C of Lely has been improved compared to the udder health report of T4C investigated in 2012. The positive predictive value appears to be 90% which means it has increased in comparison with that previous study from 2012. The number of false positive attentions has decreased to 10%. As a result, farmers are more motivated to check the attention. It turns out that 56% of the attentions were checked by the farmers, which is also a higher number compared to previous findings. However, cows are still missing on the report and therefore the report is mainly used for the detection of mastitis.

Literature

Bach, K., Sipka A., & McArt, J. A. A. (2019). Case study: Evaluate in quarter and composite milk sampling for detection of subclinical intramammary infections in dairy cattle. *Preventive Veterinary Medicine, 163*, 51-57.

Buma, K. (2012). Mastitis detection at dairy farms with a Lely Astronaut in the North-Western part of the Netherlands and the use of T4C report 'Udder health' by farmers. Master thesis, Faculty of Veterinary Medicine, University of Utrecht.

Cavero, D., Tölle, K. H., Rave, G., Buxadé, C., & Krieter, J. (2007). Analysing serial data for mastitis detection by means of local regression. *Livestock Science*, *110*(1-2), 101-110.

Enjalbert, F., Nicot, M. C., Bayourthe, C., & Moncoulon, R. (2001). Ketone bodies in milk and blood of dairy cows: Relationship between concentrations and utilization for detection of subclinical ketosis. *Journal of Dairy Science*, *84*(3), 583-589.

Hogeveen, H., Kamphuis, C., Steeneveld, W., & Mollenhorst, H. (2010). Sensors and clinical mastitis—The quest for the perfect alert. *Sensors*, *10*(9), 7991-8009.

Kamphuis, C., Mollenhorst, H., Heesterbeek, J. A. P., & Hogeveen, H. (2010). Detection of clinical mastitis with sensor data from automatic milking systems is improved by using decision-tree induction. *Journal of Dairy Science*, *93*(8), 3616-3627.

Kamphuis, C., Sherlock, R., Jago, J., Mein, G., & Hogeveen, H. (2008). Automatic detection of clinical mastitis is improved by in-line monitoring of somatic cell count. *Journal of Dairy Science*, *91*(12), 4560-4570.

Khatun, M., Thomson, P. C., Kerrisk, K. L., Lyons, N. A., Clark, C. E. F., Molfino, J., & García, S. C. (2018). Development of a new clinical mastitis detection method for automatic milking systems. *Journal of Dairy Science*, *101*(10), 9385-9395.

Jacobs, J. A., & Siegford, J. M. (2012). Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. *Journal of Dairy Science*, *95*(5), 2227-2247.

Kandeel, S. A., Megahed, A. A., Ebeid, M. H., & Constable, P. D. (2019). Ability of milk pH to predict subclinical mastitis and intramammary infection in quarters from lactating dairy cattle. *Journal of Dairy Science*, *102*(2), 1417-1427.

Kuiper, R., & Nieuwstadt, R.A. (2014). *Het klinisch onderzoek van paard en landbouwhuisdieren* (4e ed.). Amsterdam: Reed Business.

Mottram, T., A. Rudnitskaya, A. Legin, J. L. Fitzpatrick, and P. D. Eckersall. (2007). Evaluation of a novel chemical sensor system to detect clinical mastitis in bovine milk. *Biosensors and Bioelectronics, 22*, 2689–2693.

Mbithi, P. M. F., Wabacham J. K., & Mbuthia, P. G. (2008). Factors associated with the occurrence of claw disorders in dairy cows under smallholder production systems in urban and peri-urban areas of Nairobi, Kenya. *Veterinarski Arhiv*, *78*(4), 343-355.

Neave, H. W., Lomb, J., Weary, D. M., LeBlanc, S. J., Huzzey, J. M., & von Keyserlingk, M. A. G. (2018). Behavioral changes before metritis diagnosis in dairy cows. *Journal of Dairy Science*, *101*(5), 4388-4399.

Penry, J.F. (2018). Mastitis control in automatic milking systems. *Veterinary Clinics: Food Animal Practice*, *34*(3), 439-456.

Petzer, I. M., Karzis, J., Donkin, E. F., Webb, E. C., & Etter, E. (2017). Validity of somatic cell count as indicator of pathogen-specific intramammary infections. *Journal of the South African Veterinary Association*, *88*(1), 1-10.

Rutten, C. J., Velthuis, A. G. J., Steeneveld, W., & Hogeveen, H. (2013). Invited review: Sensors to support health management on dairy farms. *Journal of Dairy Science*, *96*(4), 1928-1952.

Solano, L., Barkema, H., Pajor, E. A., Mason, S., LeBlanc, S. J., Heyerhoff, J. Z., ... & Rushen, J. (2015). Prevalence of lameness and associated risk factors in Canadian Holstein-Friesian cows housed in freestall barns. *Journal of Dairy Science*, *98*(10), 6978-6991.

Steeneveld, W., van der Gaag, L. C., Ouweltjes, W., Mollenhorst, H., & Hogeveen, H. (2010). Discriminating between true-positive and false-positive clinical mastitis alerts from automatic milking systems. *Journal of Dairy Science*, *93*(6), 2559-2568.

Steensels, M., Antler, A., Bahr, C., Berckmans, D., Maltz, E., & Halachmi, I. (2016). A decision-tree model to detect post-calving diseases based on rumination, activity, milk yield, BW and voluntary visits to the milking robot. *Animal*, *10*(9), 1493-1500.

Van der Tol, R., Kool, P., Van der Kamp, A.J. (2016). When cow health counts, probabilities matter. Proceedings of the first international conference on Precision Dairy Farming, Leeuwarden, the Netherlands.

Van der Vorst, Y., Ouweltjes, W. (2003). Melkkwaliteit en automatisch melken; een risico inventarisatie. Praktijk Rapport Rundvee 28, Livestock Research, Wageningen UR.

Websites

www.stichtingkom.nl consulted on 2 December 2018

www.connecterra.io consulted on 12 April 2019

Appendix

A1. Locomotive score card

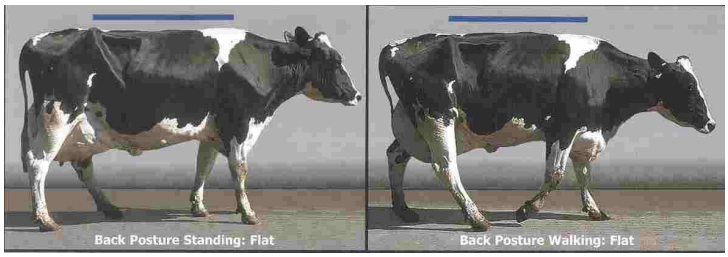
DAIRY TRAINING CENTRE

BEWEGINGSSCORE VOOR MELKVEE

BEWEGINGSSCORE 1

NORMAAL

Staat en loopt normaal



BEWEGINGSSCORE 2

LICHT AFWIJKEND

Staat met rechte rug
Loopt met gekromde rug

BEWEGINGSSCORE 3

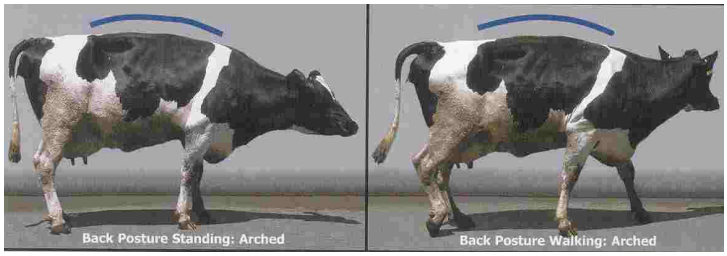
LICHTE KREUPELHEID

Staat en loopt met kromme rug

BEWEGINGSSCORE 4

KREUPEL

Eén of meerdere klauwen worden ontlast



BEWEGINGSSCORE 5
ERNSTIG KREUPEL

Weigert op een been te staan. Blijft liggen of heeft grote moeite op te staan

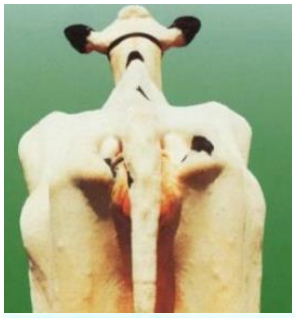
A2. Body condition score card

DAIRY TRAINING CENTRE

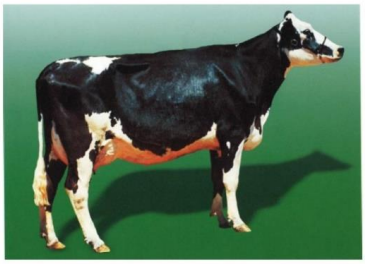
Conditiescore kaart

Een eerste uitgangspunt voor de score is de hoeveelheid vet in de koekoeksgaten en rondom de staartinplant

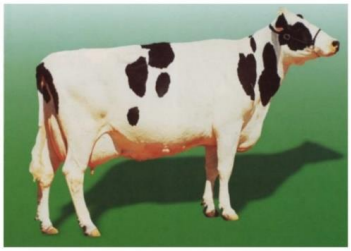
Score 1



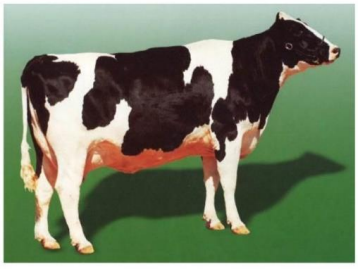
Score 2

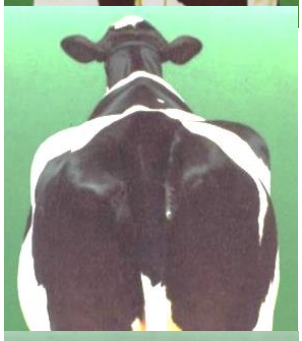


Score 3

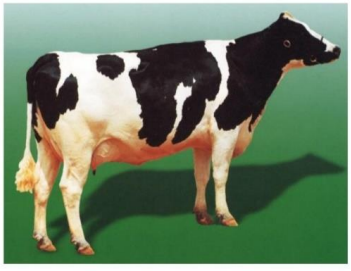


Score 4





Score 5



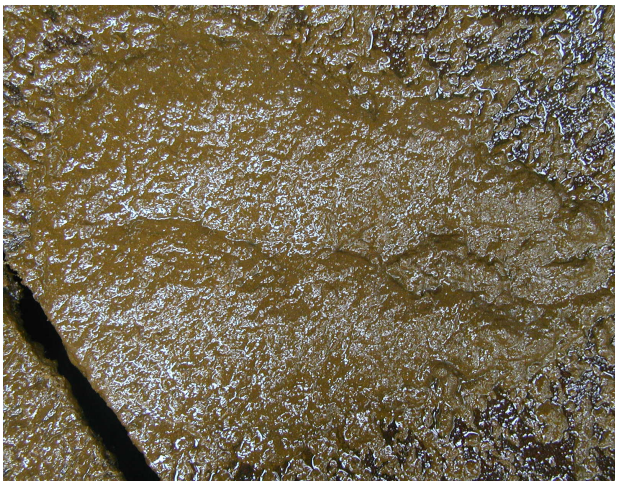
A3. Manure score card

DAIRY TRAINING CENTRE

Mestscorekaart

*Figuur 1.1: diktescore **1***

*Figuur 1.2: diktescore **1.5***



Score 1;
De mest is waterdun en de hoop is niet meer herkenbaar. Verlaat de koe als een straal. **Veel te dun.**

*Figuur 1.3: diktescore **2***

*Figuur 1.4: diktescore **2.5***

Score 2;
De mest ziet er uit als een dunne vla, en is wel als zodanig herkenbaar. De mest spettert ver uiteen. De mest verlaat de koe in een straal. **Te dun.**

Mestscorekaart

*Figuur 1.5: diktescore **3***

*Figuur 1.6: diktescore **3,5***

Score 3;
De mest ziet eruit als een dikke vla die bijeen blijft. Bij vallen klinkt een licht ploppend geluid. De dikte van de hoop is ongeveer 3 tot 4 cm. Kuiltje zichtbaar. Ringen zichtbaar. De mest verlaat de koe niet meer als een straal. **Gewenst voor een hp, mp, deels lp, koe.**

Figuur 1.7: diktescore **4**

Figuur 1.8: diktescore **4.5**

Score 4:
De mest is dik. **Mooie mest voor droge melkkoeien en pinken**

Score 4.5:
De mest ligt in stijve ballen, meer als paardenmest. **Voor droge melkkoeien en pinken te stijve mest.**

B. Questionnaire for farmers during the first visit

Vragenlijst

Gegevens veehouder

Naam veehouder	
Adres	
Telefoonnummer	
Emailadres	

Aantal melkkoeien	
AMS geplaats in jaar..	
Type AMS	
Aantal AMS	
Celgetalmeting	JA/NEE
Herkauw sensor	JA/NEE
Weegvloer	JA/NEE
Maakt u nog gebruik van sensoren die niet genoemd zijn? Zo ja welke?	
# weken/MPR	
Weidegang	JA/NEE
Bedrijfsbegeleiding/ … weken	JA, iedere … weken/ NEE
Mestschuif	JA/NEE
Afkalfhok	JA/NEE
Ziekenbox	JA/NEE
Separatieruimte	JA/NEE
# VAK op het bedrijf	

Ziekte	**Status**
BVD	
IBR	
Para-tbc	
Neospora	
Salmonella	

Kengetallen

Melkproductie (305 dagen)	
Tankcelgetal	
# behandelde klinische mastitis gevallen in 2018	
# behandelde koeien met slepende melkziekte in 2018	
# behandelde koeien met baarmoederontsteking in 2018	
# behandelde kreupele koeien in 2018	

Kengetallen robot

Gemiddeld aantal melkingen/dag	
Gemiddeld aantal attentiekoeien op de gezondheidslijst/dag	
Gemiddeld aantal mislukte melkingen/dag	
Gemiddeld aantal weigeringen/dag	

Gezondheidsrapport

Hoe tevreden bent u met het gezondheidsrapport?	
Hoe vaak per dag kijkt u op de gezondheidsrapport?	
Waar kijkt u naar als u het rapport ziet?	
Vertrouwt u op het rapport?	
Gebruikt u aanvullende informatie naast het rapport?	
Wat doet u als een koe op de lijst staat?	
Controleert u alle koeien die op het rapport staan? Zo, nee vanaf welke ziektescore controleert u de koe?	
Wanneer behandelt u de koe?	
Mist u gegevens/metingen op het rapport?	
Mist u koeien op het rapport?	

C. Interview when viewing health report during each visit

Interview

Welke koeien op het gezondheidsrapport heeft u vandaag onderzocht of was u van plan om vandaag te onderzoeken?

Onderzochte koeien

- Koe 1
    - Op basis van welke informatie zocht u deze koe op?
    - Hoe ziet uw onderzoek bij de koe eruit?
    - Wat was uw conclusie van het onderzoek?
    - Heeft u de koe behandeld?
- Koe 2 etc

Niet onderzochte koeien

- Koe 1
    - Op basis van welke informatie zocht u deze koe niet op?
    - Waarom zocht u deze koe niet op?

D. Table 1. Overview of quotes per farmer about the use of the disease probability of the health report

Table 1. Overview of quotes per farmer about the use of the disease probability of the health report

Farmer	Quote
1	Ik bekijk alle koeien die op het gezondheidsrapport staan. Ik hecht niet veel waarde aan de ziekte score. Ik kijk liever naar de koe en de melk.
2	Ik kijk eigenlijk niet naar de ziektescore. Ik hecht meer waarde aan de specifieke waardes van de attenties dan weet ik waar ik moet letten als ik de koe opzoek. Ik kijk naast het gezondheidsrapport ook naar de melkkwaliteit en de grafiek activiteit.
3	Ik kijk niet echt naar de ziektescore. Ik kijk naar de specifieke attenties en naar de ernst van die waardes. Aan de hand daarvan maak ik de beslissing of ik de koe op zoek of niet.
4	Ik kijk wel naar de ziektescore maar altijd in combinatie met het bezoekgedrag, attentie afwijking dagelijkse productie en temperatuur. Ook check ik altijd of de koe wel naar de robot komt.
5	Ik heb geen bepaalde grenswaarde in mijn hoofd voor de ziektescore. Ik kijk wel naar de ziektescore samen met de specifieke attenties maar ik bekijk de score per koe. Heeft de koe ineens een veel hogere ziektescore dan gisteren dan vind ik dat zorgwekkend. Koe met altijd een hoge geleidbaarheid vind ik minder zorgwekkend dan een koe die dat nooit heeft.
6	Ik kijk wel naar de ziektescore maar vooral ook naar de specifieke attenties. Als ik alleen de ziekte score zie dan heb ik er niet zo veel aan. Hij kijkt wel naar de ziektescore maar kijkt ook vooral naar de specifieke attenties. Want alleen de score heb je niet zo veel aan. Hij mist wel koeien op het rapport met slepende melkziekte.

E. Table 1. Detailed overview of the examined cows on the health report

Table 1. Detailed overview of the examined cows on the health report

Farm	Cow number	Lactation days	Disease score	Specific attentions T4C	Finding	Classification
1	17	100	88	Conductivity RV 91 Ruminating activity 83 Milk production decline -21,8 Residual food 51 Fat/protein ratio 1,43 Mastitis RV	Clinical mastitis	Sick
	8	11	63	Conductivity RA 91 Milk production decline -1,4	Clinical mastitis	Sick
	6	359	10	Ruminating activity 66	Healthy	Healthy
	8	19	11	Milk trend first 21 days 67 Fat/protein 1,04	Clinical mastitis	Sick
2	144	400	10	Conductivity 109 Mastitis LV	Clinical mastitis	Sick
	20	6	29	Milk trend first 21 days 56 Fat/protein 0,79	Ketosis	Sick
	118	2	87	Milk production decline -4,2 Conductivity LA 101 Mastitis LA	Subclinical mastitis	Sick
	126	-	-	Mastitis RA Conductivity RA 93	Clinical mastitis	Sick
	118	8	-	Conductivity LV 84 Conductivity RV 95 Conductivity LA 94	Clinical mastitis	Sick
	20	13	19	Milk trend first 21 days 60 Fat/protein 0,94	Ketosis	Sick
	67	108	17	Milkproduction decline -16,8	Lame	Sick
	20	19	33	Milk trend first 21 days 62 Fat/protein 0,9	Ketosis	Sick
3	121	133	11	Milk production decline -4,5 Conductivity RV 84	Clinical mastitis	Sick
	285	105	11	Milk production decline -3,8 Temperature 39,8	Healthy	Healthy
	305	209	23	Temperature 40,1 Conductivity LA 98	Subclinical mastitis	Sick
	29	15	10	Fat/protein ratio 1,64 Temperature 39,3	Ketosis	Sick
	303	183	18	Conductivity LV 99 Mastitis LV	Clinical mastitis	Sick
	55	90	12	Milk production decline -4,1 Fat/protein ratio 1,03 Temperature 39,2	Healthy	Healthy
	121	141	12	Temperature 40,7 Conductivity RV 83	Subclinical mastitis	Sick
	210	147	25	Temperature 39,7	Fever	Sick

				Milk production decline -8,5		
4	58	264	17	Milkproduction decline -	Lame	Sick
	122	35	23	Milkproduction decline -8,2	Lame	Sick
	90	262	54	Milkproduction decline -11,2 Conductivity LV 95 Time away 29;27 hour	Subclinical mastitis	Sick
	115	256	97	Activity 47 Milk production decline Conductivity RV 100	Clinical mastitis	Sick
	253	10	74	Milk production decline -3,2 Temperature 39,4 Residual food 40	Healthy	Healthy
	9979	207	25	Milk production decline -13,7	Clinical mastitis	Sick
	9968	276	15	Conductivity LA 97 Mastitis LA	Subclinical mastitis	Sick
	9917	184	23	Activity 68 Milk prodcution decline -4,4	Subclinical mastitis	Sick
	9854	152	31	Activity 64 Milkproduction decline -5,3 Residual food 46	Lame	Sick
	111	173	11	Milkproduction decline -4,4 Conductivity RA 89	Lame	Sick
5	101	354	41	Milk production decline -6,7 Conductivity RA 84	Subclinical mastitis	Sick
	40	257	20	Conductivity LA, RA 94 Mastitis RA	Subclinical mastitis	Sick
	27	203	14	Conductivity LA 93	Subclinical mastitis	Sick
	41	7	13	Milktrend 73 Fat/protein ratio 1,04	Metritis	Sick
	49	305	11	Conductivity RA/LA/RV 103 Mastitis RV	Subclinical mastitis	Sick
	79	227	20	Conductivity RA 98 Mastitis RA	Subclinical mastitis	Sick
	41	15	13	Milktrend 15	Lame/Metritis	Sick
	112	64	15	Milk production decline -9,6	Thin manure	Sick
	38	53	11	Milkproduction decline -8,8	Thin manure	Sick
6	1542	230	15	Milkproduction decline -9,8	Thin manure	Sick
	1464	46	17	Milkproduction decline -6,5 Fat/protein ratio 1,04	Ketosis	Sick

F. Table 1. Detailed overview of the randomly selected visually assessed sick cows not on the health report

Table 1. Detailed overview of the randomly selected visually assessed sick cows not on the health report

Farm	Cow number	Abnormal observation	Finding
1	20	No straight back, walks stiff and careful. Locomotion score 3.	Lame
	17	Stands and walks with a crooked back. Locomotion score 3	Lame
	17	Stands and walks with a crooked back. Locomotion score 3	Lame
2	13	Left hind leg crippled. Sometimes slides away and is loaded less than the right hind leg. Locomotion score 4	Lame
	10	Left hind leg shortened pass Locomotion score 4	Lame
	48	Left hind leg shortened pass, walks with a crooked back Locomotion score 4	Lame
3	143	Right hind leg shortened pass, walks with a crooked back Locomotion score 4	Lame
4	9969	Stands and walks with a crooked back. Right hind leg is loaded less than the left hind leg. Locomotion score 4	Lame
	9944	Stands and walks with a crooked back. Right hind leg is loaded less than the left hind leg, loaded right hind leg very short Locomotion score 4	Lame
	158	Stands on the tip of the claw of left hind leg. Load as little as possible on the left hind leg. Locomotion score 5	Lame
	74	Stands and walks with a crooked back. Right hind leg is loaded less than the left hind leg, loaded right hind leg very short and a shortened pass Locomotion score 4	Lame
	53	No straight back, walks stiff and careful. Locomotion score 3.	Lame
	114	Body condition score 1	Sick
5	106	Stands and walks with a crooked back, relieves left hind leg when standing still. Locomotion score 3	Lame
	111	Dirty fur at the back Manure score 2	Thin manure
	-	Stands and walks with a crooked back, shortened pass Locomotion score 3	Lame
	34	Left hind leg shortened pass, walks with a crooked back Locomotion score 4	Lame
	45	Body condition score 1 Manure score 1	Thin manure

	53	Dirty fur at the back Manure score 1/2	Thin manure
	92	Dirty fur at the back Manure score 1/2	Thin manure
	61	Dirty fur at the back Manure score 1/2	Thin manure
	-	Dirty fur at the back Manure score 1/2 Body condition score 2	Thin manure
	37	Left hind leg shortened pass, walks with a crooked back Locomotion score 4	Lame
6	38	Body condition score 1	Sick

G. Table 1. Deviating threshold values of the T4C settings of the farmers

Table 1. Deviating threshold values of the T4C settings of the farmers							
Deviating threshold value	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**	**Farm 6**	**Standaard value**
Maximum permitted deviation from the 24-hour milk yield (KG)	3	3	-[1]	-	-	3	4
Maximum permitted deviation from the 24-hour milk yield (%)	15	15	15	-	-	15	20
Permitted deviation of measured values (acute attention) (%)	-	15	10	-	15	15	20
Permitted deviation from average conductivity (acute attention) (%)	10	5	10	10	10	5	20
Threshold conductivity	-	90	90	-	90	90	100
Show all cows with a daily production drop greater than x kg	-	4	3	5	-	4	7
-[1]= standaard value							