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Technical and Economic Effects of Culling and Reproductive Strategies
in Dairy Cattle Herds Estimated by Stochastic Simulation

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The objective of this study was to create operational replacement guidelines under various conditions concerning reproductive performance, supply of replacement heifers and individual milk yield. Nine culling strategies were defined by three average insemination periods and by three discrimination policies between high and low yield cows. The effect of the nine culling strategies was analyzed with combinations of heat detection rate and time of initiation of breeding after calving under two replacement heifer purchase policies: purchase (open herd) and no purchase (closed herd). The strategies were evaluated using a stochastic simulation model which simulated production and reproductive status in herds composed of dual purpose cattle with additional young stock. The evaluation of the strategies was made in a situation without a milk quota under typical danish conditions in 1993. Results showed that discriminating between high and low yield cows improved net revenue significantly in open herds but not in closed herds. Irrespective of the purchase policy using longer insemination periods increased net revenue significantly in herds with poor reproductive performance. Whereas net revenue in herds with good reproductive performance tend to increase by using shorter insemination periods. The culling rate is a poor figure when evaluating
culling strategies and culling strategies should be assessed at herd level rather than per cow.

Key words: replacement, economics, stochastic simulation.
Introduction

The dairy farmer is constantly confronted with replacement decisions. He has to decide whether a particular cow should be kept or replaced by a down calving heifer. The replacement problem is closely related to the reproductive performance of the herd. That is, the replacement rate is likely to be increased with reduced reproduction, because non-pregnant cows are expected to produce less milk in the future and therefore are candidates for culling. Replacement rate and reproductive performance are also related in that increased culling and reproductive performance will both increase the number of calves born in the herd.

The replacement problem has been studied by dynamic programming models (Van Arendonk, 1985; Kristensen, 1993) and stochastic simulation models (Dijkhuizen & Stelwagen, 1988; Marsh et al., 1987). The studies based on dynamic programming (e.g Van Arendonk, 1985; Kristensen, 1993) have dealt with the replacement problem assuming an unlimited supply of replacement heifers. The impact of a limited supply of replacement heifers has been studied by Ben-Ari & Gal (1986) as well as Kristensen (1992) who concluded that it is not realistic to consider the replacement problem independently of the actual supply of replacement heifers from the herd. In practice the supply of heifers is often limited as many herds are reluctant to buy heifers due to the risk of introducing infectious diseases in the herd. When cows are culled voluntarily and replacement heifers are not available the herd size will change.
In stochastic a simulation model it is possible to treat culling and recruitment of heifers separately, allowing this specific aspect of the culling problem to be studied.

An important culling criteria for a cow is her milk production relative to herd average. Accordingly, several previous studies (e.g. Van Arendonk, 1985; Kristensen, 1993) have described the influence of variation in milk production on the replacement decision. In Denmark cows are usually fed a fixed amount of feed based on their stage in lactation and not on their actual milk production. Therefore, in many herds, low producing cows are fed at a higher energy level than is justified by their milk yield. Culling candidates therefore, may have relatively high weight gain, which impacts the economic evaluation of culling strategies.

Replacement strategies have been analyzed by methods such as the marginal revenue approach (Dijkhuizen et al., 1985) and dynamic programming (Van Arendonk, 1985; Kristensen, 1993). An advantage of dynamic programming is the ability to calculate very detailed optimal strategies identifying individual cows for culling. More powerfull PC's make dynamic programming model applicable also for decision support. Some dairy herd may, however, still ask for more simple strategies for culling. Dynamic stochastic simulation which has been applied by e.g. Marsh et al. (1987) and Dijkhuizen & Stelwagen (1988) has proved to be a suitable tool for testing such strategies under various conditions.

A dynamic stochastic model simulates herd performance indirectly by aggregating individual cow and heifer performance. It is then possible to simulate the effects
of management strategies on herd output and economic efficiency. Sørensen et al. (1992) describe a dynamic stochastic model, SIMHERD, which relates the replacement problem to heifer production as well as culling criteria for cows. SIMHERD analyses the replacement problem under a detailed management strategy in which production is a function of preplanned feeding.

The purpose of this paper is to create operational replacement guidelines under various conditions concerning reproductive performance, supply of replacement heifers and individual milk yield. Furthermore, the specific feeding of cows chosen for culling is taken into account. Several previous studies have considered some of the aspects mentioned, but none of them have simultaneously considered the effect of the supply of heifers, the reproductive performance and the feeding strategy for cull cows.

The strategies constructed were evaluated using the SIMHERD model. The results presented refer to a situation without a milk quota.
Materials and Methods

The model

SIMHERD is a stochastic dynamic model for simulating production and reproductive status in a dairy herd with additional young stock (Sørensen et al., 1992). Production changes in the herd are simulated through changes in reproductive status in an individual cow. In the model individual outcomes of discrete events such as heat detection rate, conception, fetal death and sex and viability of the calf are triggered stochastically. That is, a random number drawn from a relevant probability distribution determines whether an event takes place or not. Time intervals are 7 days. No relationship is assumed between milk production and reproductive performance and between reproductive events in successive lactations. That is the conception rate is constant and equal for all animals in the herd. The heat detection rate is defined as the number of oestrus events observed divided by the number oestrus events occurring.

Each identified animal in the model has a specified genetic milk production potential which does not change over time. Individual variation in milk production is produced by assigning a random value from a normal distribution to the milk production potential of the heifer at birth. At each calving a value from a normal distribution is drawn to create variation between lactations for a particular animal. Actual milk production depends on the genetic milk production potential, available energy from feed intake and a rule for distribution of energy between lactation and
growth. An animal's status is defined by her age, lactation stage, lactation number, oestrus status, pregnancy status, eligibility for culling, milk production potential, milk production and live weight.

System behaviour as simulated in the model is controlled by the state of the initial herd and assignment of decision variables. The model contains 148 decision variables organized in eight categories: biology, lactation-growth parameters, health, reproductive strategy, culling strategy, feeding strategy for cows, feeding strategy for heifers and feeding plans for cows and heifers.

Feeding in the model is not based on production requirement calculations, but is specified by a feeding regime. A typical feeding regime in the model specifies a fixed level of concentrate per day and roughage ad lib. for the first 24 weeks of lactation independent of current milk yield. The amount of concentrate can be varied by lactation number. Roughage intake is determined by quality of the feed stuff, parity and stage of lactation. After 24 weeks of lactation the amount of feed is reduced if current milk yield drops below a predefined threshold specified separately for first and later lactations. The feeding regime allows for two feed reductions prior to drying off. Cows chosen for culling can be fed independently of current milk production so that their potential for weight gain may be fully utilized.
Reproductive strategy is determined by the age of heifers and for cows, the number of days post-calving, when they are first considered eligible for insemination. Heat detection rate can be adjusted according to cow age and the season.

The insemination period is the length of time during which attempts are made to breed the heifer or cow until it is decided to cull her for unacceptable days open. It can be considered as "the acceptable days open". A cow is picked for culling, if her insemination period exceeds a threshold, which can vary for high and low yield cows according to milk production in their current lactation. Any extended insemination period allowed for high yield cows compared to low yield cows is defined as the "discrimination difference". A culling candidate (a cow identified for culling) is not bred and is replaced when a down calving heifer is ready to enter the herd. A cow is also culled if the threshold for days open is exceeded or if her milk production is below the threshold for drying off a pregnant cow. Regardless of their lactation stage and production yield, all cows are at risk of involuntarily culling from unforeseen events.

All bull calves are sold at birth. The number of female calves entering the herd depends on the probability for female offspring and the survival rate at birth. Heifers are sold if they are not pregnant after reaching the threshold age for pregnancy. All other heifers are kept until one week prior to expected calving. A down calving heifer is included in the herd if the actual number of cows is less than the specified maximum or there is at least one available culling candidate.
Otherwise the down calving heifer is sold. If herd size drops below the minimum and no heifer is available to enter the herd, a down calving heifer will be purchased. Heifers are more often purchased when the minimum herd size is set close to the maximum.

**Experimental design**

In practice a cow is usually culled if she fails to conceive within a predefined insemination period. The insemination period is seldom equal for high and low yield cows, and high yield cows are often allowed a longer insemination period. In this study the economic effects of a 0, 42 and 84 days longer insemination period for high yield cows than for low yield cows were studied at three average insemination periods (168, 210 and 252 days). The longer insemination for high yield cows compared to low yield cows was referred to as the "discrimination difference" between high and low yield cows. A high yield cow was defined as a cow with milk production above the herd average. The nine culling strategies are shown in Table 1.

The replacement problem is a compromise between the supply of replacement heifers and the number of culling candidate cows. The misfit between culling and supply causes a fluctuation in herd size over time. While some producers will accept a relative low herd size before purchasing down calving heifers, other farmers will accept only a limited decrease in herd size. The first type of producers give their own reared heifers a high priority, and their herd can be regarded as
"closed" whereas the second type has an "open" herd. Two different production systems illustrating these attitudes to herd size fluctuation were defined a closed herd in which maximum number of cows equalled 50 and the minimum number equalled 35 and an open herd in which maximum number of cows was 50 and the minimum number was 49.

Nine levels of reproductive performance were defined by three heat detection rates (30, 50 and 70%) and three times for initiation of breeding after calving (28, 42 and 56 days).

Each of the nine culling strategies was analyzed in 15 combinations of production system, heat detection rate and initiation of breeding after calving. A heat detection rate of 30% was not simulated in the closed herd because it would not have been possible to maintain herd size under those conditions.

All of the 135 scenarios were simulated for a period of 10 years and replicated 10 times.

The initial herd was composed of typical dual purpose cattle. The herd size equalled 50 cows. 35% of the cows were in first lactation. No seasonal calving patterns were assumed. The average age at first calving was 26 months. The milk production potential in 308 days of lactation was 7000 kg FCM. The conception rate and heat detection rate equalled 50%. Initiation of breeding began 42 days post partum. A pregnant cow was dried off if she was less than 49 days from
calving or her milk production was less than 5 kg FCM. Open cows were pointed out for culling 240 days post partum irrespective of their milk production. The maximum days open before culling was 392 days. The involuntary culling rate equalled 20%. The feeding regime applied in the herd is shown in Table 2. It is important to stress that the actual feed intake of the cow depended on the bulk capacity of the cow and was less than the amount of feed given to the cow.

Since the effects of a certain strategy can be seen at the herd level only after the passage of time, only the results from year 6 through 10 were used in the subsequent statistical analyses.

Net revenue was calculated as sales income less variable costs of feed, insemination and miscellaneous costs for cows as well as for heifers. The cost for home grown feeds were opportunity costs for a sales crop. The sales values were corrected for variation in herd size and value at the end of the year. Labour costs were not included as a variable cost. The applied prices and costs are shown in Table 3.

Statistical analysis

The data were analyzed by the SAS GLM (general linear models) procedure (SAS Institute Inc, 1982).
The economic impacts of various culling strategies, heat detection rates and initiation times of breeding after calving were analyzed using the model shown in equation 1.

\[ Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \alpha\beta_{ij} + \alpha\gamma_{ik} + \alpha\delta_{il} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl} + \epsilon_{ijkl} \]  

(1)

Where \( Y_{ijkl} \) = Net revenue,

\( \mu \) = Mean value of \( Y \),

\( \alpha_i \) = Effect of heat detection rate,

\( \beta_j \) = Effect of initiation time of breeding for cows,

\( \gamma_k \) = Effect of average insemination period,

\( \delta_l \) = Effect of discrimination difference, and

\( \epsilon_{ijkl} \) = Residual value.

For a better understanding of the economic main effects of the different culling strategies ("discrimination difference" and average insemination period). The model shown in equation 2 was applied for a more detailed analysis of some technical and economic key figures at three different reproductive performances. The model is a partial model of the model shown in equation 1.
The reproductive performance was rated as follows:

- **Good** when the heat detection rate equalled 70% and breeding was initiated 28 days after calving.

- **Moderate** when the heat detection rate equalled 50% and breeding was initiated 42 days after calving.

- **Poor** when the heat detection rate equalled 30% and breeding was initiated 56 days after calving.

\[ Y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijk} \]  

(2)

Where \( Y_{ijk} \) = Culling rate, weight of culled cows, total milk production, net revenue,

\( \mu \) = Mean value of \( Y \),

\( \alpha_i \) = Effect of average insemination period,

\( \beta_j \) = Effect of discrimination difference between high and low yield cows and,

\( \varepsilon_{ijk} \) = Residual value.
Results

The main effects of the culling strategies i.e. the results from model two are presented first.

Technical results of nine culling strategies at three levels of the reproductive performance in two production systems

The results of the statistical analysis showed that in open herds the "average insemination period" and "discrimination difference" had a significant effect (p-value < 0.05) on most technical key figures (herd size, milk production, culling rate, cull weight and feed consumption). However, "discrimination difference" did not affect cull weight significantly at poor reproductive performance. The impact of "discrimination difference" and "average insemination period" did not differ between open and closed herds except that cull weight in closed herds was not significantly affected by "discrimination difference" at any level of the reproductive performance.

Average herd size, calculated as the average number of cows in the herd per year, showed small systematic variations between herd management strategies. Improved reproductive performance increased the average annual herd size by 0.3 cows in open herds and by 0.6 cows in closed herds. Fig. 1 shows the effects of reproductive performance (good, moderate or poor) and culling strategies (Table 1) in open and closed herds. Note that the graphs are not arranged in the same way.
Some graphs are arranged from good to poor reproduction while other graphs are arranged from poor to good reproduction.

For both herd replacement strategies, the culling rate decreased when the average insemination period was extended and when reproductive performance improved. The culling rate was generally higher with a larger "discrimination difference".

With moderate and good reproductive performance, the body weight of culled cows increased with increasing insemination period because cows were removed at a later stage of lactation. Conversely with poor reproductive performance, the weight of culled cows decreased when the insemination period was extended. With short insemination periods cows were picked for culling early in lactation but were kept in the herd for a longer period of time due to the limited supply of replacement heifers. Since cows chosen for culling were fed at a higher energy level than was appropriate for their production, they had a high cull weight with the short insemination period. The cull weight was affected by the "discrimination difference" between high and low yield cows due to the effect of "discrimination difference" on culling.

When the average insemination period was short and the reproductive performance improved from poor to moderate, the average weight of culled cows decreased by 50 kg. Since there was a larger supply of replacement heifers than needed for replacement, cows chosen for culling were eliminated much earlier in the lactation period at moderate reproductive performance than with poor reproductive perform-
ance. For the longer insemination periods the disproportionately fewer cows were
picked for culling, and cull cows were fed a high energy ratio for a shorter period.
Therefore the effect of improved reproduction on cull weight was reduced to 10 kg.

In general annual milk production per year rose with improved reproductive
performance, increased "discrimination difference" and decreased insemination
period. The decrease in annual milk production with increased "discrimination
difference" in closed herds with moderate reproductive performance and short
insemination periods was caused by a decrease in herd size. The difference in
annual milk production between the three average insemination periods which was
found in open herds with poor reproductive performance was not statistically
significant. There was no obvious explanation for the low milk production caused
by culling strategy 5 (a moderate insemination period and a moderate "discrimina-
tion difference" between high and low yield cows) in open herds with moderate
reproductive performance.

Data are not presented graphically, but the number of down calving heifers sold
increased with improved reproductive performance, longer insemination period
length and decreased "discrimination difference" between high and low yield cows.
Economic effects of nine culling strategies at three levels of the reproductive performance in two production systems

The net revenue from nine culling strategies at the three levels of the reproductive performance are shown in Fig. 2. Net revenue increased with improved reproductive performance, however at a diminishing rate.

In open herds, net revenue rose significantly with increased "discrimination difference" irrespective of the average insemination period and the reproductive performance of the herd. "Discrimination difference" had no statistical significant impact on net revenue in closed herds.

In closed herds with moderate reproduction and in open herds with poor reproduction extending the insemination period increased net revenue significantly due to an increased herd size. The average insemination period had no significant effect on net revenue in closed herds with good reproduction and in open herds with moderate or good reproduction.

Interaction effects between culling strategy and aspects of reproductive performance on economic return

Delayed initiation of breeding after calving decreased herd net return. The magnitude of the decrease depended on the heat detection rate and the production system (closed versus open herd) as shown in Fig 3. The decreased net revenue at
the 50% compared to 70% heat detection rate in closed herds was caused by reduced herd size.

Differences between the insemination periods declined with improved heat detection efficiencies. Since at high heat detection rates most cows will soon be impregnated, extending the insemination period has a limited effect. Due to the effect on herd size, increasing the insemination period from short to moderate had a large economic effect in closed herds with poor heat detection rate.

Increasing the "discrimination difference" in open herds improved net revenue irrespective of the level of the heat detection. Increased "discrimination difference" in closed herds improved the net return only with good heat detection rate (70%). At 50% heat detection, increasing the "discrimination difference" reduced herd size thereby decreased revenue production.

"Discrimination difference" and average insemination period also interacted with the initiation of breeding after calving in closed herds as shown in Fig. 4. Extending the insemination period increased net revenue if breeding was initiated 42 or 56 days after calving, but decreased returns if breeding began 28 days after calving. It appears from Fig. 4 that the economic impact of the "discrimination difference" was heavily influenced by the post calving breeding interval.
Discussion

If the stable capacity is an important constraint to production a high culling rate is usually recommended compared to a milk quota situation under the same conditions concerning the reproductive performance (Kristensen, 1993). In general, however, the culling rate is a poor figure for evaluation of the culling strategy because a change in the rate may be caused by several underlying effects. Thus, results from this study suggested that a reduced culling rate would have a positive economic effect if accompanied by improved reproductive performance. On the other hand, a reduced culling rate could have a negative impact if it were accomplished by imposing less strict culling criteria.

This study found that willingness to purchase replacement heifers increased revenue. Since in practice culling criteria are often more flexible when the herd size is low, the herd size effect in a closed herd may have been overestimated in this study. The risk of imported diseases is likely to be higher in an open herd. This risk was also not incorporated to our study.

Our data suggest that a longer insemination period should be utilized when reproductive performance is moderate or poor but that a short insemination period is appropriate when reproductive performance is good. This conclusion agrees with the findings of Dijkhuizen & Stelwagen (1988) and Marsh et al. (1987).
The economic value of discriminating between high and low yield cows depended on the production system, the level of the heat detection rate and in closed herds also on the initiation time of breeding. The effect of discrimination on milk yield was lower in closed herds than in open herds because cows culled in closed herd were not always replaced by a down calving heifer. Like the study of Marsh et al. (1987) our study showed that discriminating on milk yield had more impact at poor reproduction than at good reproduction. Conversely, Dijkstraizen & Stelwagen (1988) found that the value of incorporating milk yield into the culling strategy was smaller at poor than at good reproductive performance. The differences in results may be caused by differences in the conditions under which the experiments were performed (American, Danish and Dutch respectively).

The dairy herd replacement problem was studied as a function of culling criteria and replacement supply. When the restocking supply was limited, herd size was reduced. The economic impact of this effect depended on the farmers willingness to purchase replacement heifers. Given the systematic differences associated with herd size found in our study, economic results should be evaluated at herd level rather than per cow.

The different culling strategies were evaluated in a dual purpose herd. In a herd composed of cattle specialized for milk production the value of a cull cow is lower than in a herd composed of dual purpose cattle. Therefore, the highest economic ranking insemination period may be expected to be shorter in herds specialized on milk production than in herds composed of dual purpose cattle.
Jakobsen & Enevoldsen (1992) showed that some Danish herds started insemination as early as 4 weeks post partum. The pregnancy rate may, however, be lower at this stage of lactation than at later stages of lactation. This was not included in our study therefore the economic value of starting insemination 4 weeks post partum may be slightly overestimated.

Replacement heifers were not reared for sale but as a potential for replacement in this study. Thus a surplus of heifers will increase the possibility of having replacement heifers available when it is needed. Being a surplus marked the down calving heifer price may or may not reflect the cost price. In the present study the marked price of a down calving heifer is 140 Dkr higher than the calculated cost price of rearing replacement heifers. Given the marginal difference and the small difference in the number of young stock reared across the scenarios the price on surplus heifers does not affect the ranking of the culling strategies.

No attention was payed to seasonal variation in our study. Other studies (Arendonk, 1985; Jalvingh, 1993) which have taken seasonal variation in production and prices into account have concluded that under Dutch conditions longer insemination periods should be allowed for cows which are expected to calve in seasons where milk production and/or milk price is expected to be high.

The reliability of the average outcome of the model depends on the number of replicates. Marsh et al. (1987) used 6 replicates and Dijkhuizen & Stelwagen (1988) used 20 replicates. In our study 10 replicates were used per point and each response was based on three points.
Conclusion

Based on the results from this study it can be concluded that discriminating between high and low yield cows improves net revenue significantly when the supply of replacement heifers is unlimited. In herds with limited supply of replacement heifers discriminating between high and low yield cows has no significant effect on net revenue although net revenue tends to increase by increased discrimination at good reproductive performance.

Using longer insemination periods improves net revenue when the reproductive performance is poor. As the reproductive performance improves a shorter insemination period can be allowed. In general a longer insemination period should be allowed in herds with a limited supply of replacement heifers than in herds with an unlimited supply of replacement heifers.

Based on this study it may also be concluded that the culling rate is a poor figure when evaluating culling strategies and that culling strategies should be evaluated at herd level rather than per cow.

References


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<tr>
<th>Number</th>
<th>Average herd insemination period</th>
<th>&quot;Discrimination difference&quot; between high and low yield cows</th>
<th>Insemination period (days after calving)</th>
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<td>Low yield cows</td>
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Table 2. The feeding regime applied in the herds

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<th>Lactation stage: 1-24 week post partum</th>
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<th>Cull cows</th>
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<td>Grazing, first year</td>
<td>Dkr/day</td>
<td></td>
<td>1.58</td>
<td></td>
</tr>
<tr>
<td>Grazing, second year</td>
<td>Dkr/day</td>
<td></td>
<td>2.03</td>
<td></td>
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<tr>
<td><strong>Other costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cows</td>
<td>Dkr/cow/year</td>
<td></td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Heifers</td>
<td>Dkr/heifer/year</td>
<td></td>
<td>100</td>
<td></td>
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<tr>
<td>Insemination</td>
<td>Dkr</td>
<td></td>
<td>120</td>
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<tr>
<td>Interest rate on the herd</td>
<td>%</td>
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<td>10</td>
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Fig. 1. Effects of differing reproductive performances (good, moderate poor) and culling strategies in open and closed herds.
Fig. 2. Net revenue at differing reproductive performances and culling strategies in open and closed herds.
Fig. 3. Interaction effects on net revenue between heat detection rate (30, 50 or 70%) and initiation of breeding; heat detection rate and average insemination period and between heat detection rate and "discrimination difference" in open and closed herds.
Fig. 4. Interaction effects on net revenue between initiation of breeding (28, 42 or 56 days after calving) and average insemination period and between initiation of breedings and "discrimination difference" in closed herds.