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Dynamic probabilistic simulation of dairy herd management practices. II. Comparison of strategies in order to change a herd's calving pattern

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ABSTRACT

A dynamic probabilistic simulation model is further extended and used for a comparison of different strategies in order to change the calving pattern of a herd. The Markov chain approach is used to simulate herd dynamics. Strategies to change the calving pattern focusing on the farm's intake of replacement heifers, allowing a certain variation in age at first calving, are compared. A method has been developed which allows the tuning of the available replacement heifers to the desired heifer calving pattern, using linear programming. In the basic analysis a spring calving herd is changed into an autumn calving herd. The difference in gross margin per cow per year between the starting and the desired situation is Dfl. 115. The strategy that allows the largest variation in age at calving is fastest in changing the calving pattern. It takes 9 years to realise the desired herd calving pattern, while the desired heifer calving pattern is reached after 2 years. This strategy is also the most profitable one. When considering a period of 10 years, this strategy on average yields Dfl. 105 per cow per year. For a strategy that does not allow changes in the initial age at calving, the increase is only Dfl. 6 per cow per year after 10 years, while in the previous years the costs of changing exceed even the benefits. An additional measure which does not allow cows to be inseminated in certain months during the first few years, shows not to be economically attractive.

Key words: Dairy cattle; Management; Calving pattern; Simulation

INTRODUCTION

Dairy farmers can increase their income by producing particularly in those periods of the year that have higher revenues or lower costs. Jalvingh et al. (1993) developed a dairy herd simulation model and made static comparisons of seasonal herd calving patterns. They concluded that under the current

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Dutch conditions it is best to concentrate calvings in autumn, which is mainly due to seasonal variation in milk price.

The calving pattern of a herd can be changed in different ways, either focusing on cows or on young stock. Considering cows, the calving interval can be changed. With young stock, the age at first calving can be varied along with the proportion of newly-born heifer calves which are kept for replacement at different times throughout the year. Additionally, cows and young stock can be purchased or sold. From interviews with farmers, it became clear that they prefer actions with respect to young stock in changing the calving pattern.

Until now calculations on the profitability of changing the calving pattern were restricted to a comparison of the profitability of the starting and the desired situation (Mandersloot et al., 1987; Wunder and Orth, 1989), combined with an enumeration of costs of individual measures (e.g. costs of lengthening calving interval or the rearing period with one month) (Strandberg and Oltenacu, 1989; Schmidt, 1989). The objective of this paper is to investigate the importance of studying the consequences of actually changing the calving pattern of the herd as well. These consequences are difficult to judge beforehand, as they are revealed in various revenue and cost items and spread through time. A simulation model can offer help in determining whether it is profitable to change the calving pattern. In this paper, the model of Jalvingh et al. (1993) is extended and used for a comparison of strategies for changing the calving pattern. The model allows for a farm-specific approach taking into account biological variability and different management practices. The paper describes an integrated modelling approach that (a) simulates the herd in the starting situation, (b) determines the desired calving pattern and (c) examines the costs and benefits through time of strategies that can be used to change the calving pattern. The number of options to change the calving pattern, however, is too large to include them all. Attention, therefore, is limited to the strategies concerning the intake of young stock into the herd. The modelling approach as such, however, is flexible enough to include other strategies and conditions.

MATERIAL AND METHODS

General

For determining the consequences of a strategy that changes a herd's calving pattern, the situation to start from (starting situation), the situation to go to (desired situation) and the strategy to realise the desired situation need to be defined. The dairy herd model of Jalvingh et al. (1993) is used as a basis to simulate the consequences of a strategy. Some extensions were made to make the model more flexible for strategies concerning the farm's intake of replacement heifers, using the linear programming technique.

Replacement heifer model

In the dairy herd model, animals that are culled are replaced by springing heifers to maintain herd size. The herd size is kept constant on an annual basis but may vary within a year by allowing non-immediate replacement. The distribution of heifer calvings over calendar months depends on a given pattern. The number of replacement heifers entering the herd is calculated in such a way that given the calving pattern the herd size is kept constant on an annual basis.

The strategies to change the calving pattern focus on the intake of replacement heifers into the herd. In the original dairy herd model it is assumed that there are always enough heifers available for replacement. In changing the calving pattern, this assumption no longer holds; the available replacement heifers are required to originate from herd calvings in the past. Therefore, simulation of replacement heifers from birth to calving is added to the model in order to make the number of available heifers dependent on calves born in the past. Planning of the intake of replacement heifers is a complicated matter. Therefore, a method has been developed which allows the tuning of available replacement heifers to the desired calving pattern.

Simulation of young stock

Of the calves born in the dairy herd model, 50% are females, 3% of the births concerns twins and 88% of first calving cows bear a calf that survives the first week. For older cows the calves' survival rate is 96%. The remainder makes up the potential for replacement. During the rearing period 7.5% of the young stock is culled annually. In case the length of the rearing period is not modified intentionally, the remaining heifers calve at the age of 23, 24 and 25 months, at a rate of 25%, 50% and 25% respectively. At the moment of calving it is decided which heifers will enter the herd. For the economic calculations replacement heifers are valued at market (i.e. cost) price, implying that the rearing of young stock is not an activity included in the dairy herd enterprise (Jalvingh et al., 1993).

The tuning of available heifers to the desired calving pattern

When following the herd through time, the intake of replacement heifers per year is focused on keeping the average number of cows (ANC) present in the herd constant on an annual basis. At the start of each year calculations are carried out to determine this intake of heifers in terms of number of heifers calving per month. A schematic overview of these calculations is presented in Fig. 1.

In the first step the ideal intake is calculated. The ideal intake represents the intake that keeps the average herd size constant on an annual basis and matches the desired heifer calving pattern. The herd is followed during one year without carrying out replacement of culled animals. The resulting short-

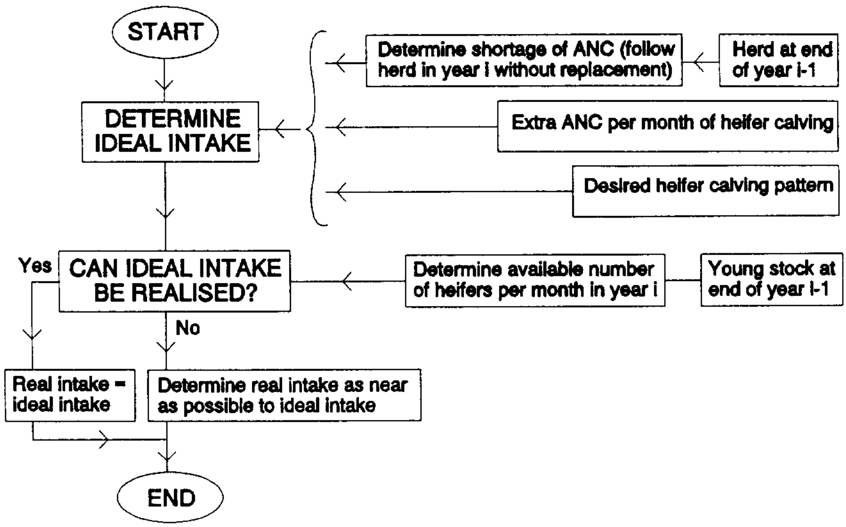

Fig. 1. Schematic overview of calculations at start of year i to determine the intake of heifers per month in year i.

TABLE 1

Extra average number of cows in rest of the year when heifer calves in a specific month

Apr[1]	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
0.75	0.71	0.66	0.60	0.54	0.49	0.46	0.40	0.33	0.25	0.16	0.08

[1]In the calculations a year runs from April to March.

age in ANC should be compensated for by the heifers that enter the herd during that year. For each calving month of a heifer the number of extra ANC a heifer realises in the rest of the year is known, taking into account the probability of disposal (see Table 1). The shortage of ANC, the extra ANC per heifer calving in a certain month and the desired heifer calving pattern, are combined into the ideal intake of heifers for each month of that year (Fig. 1).

In the second step it is determined whether the calculated ideal intake can be realised with the available heifers. From available young stock at the beginning of the year, it is determined how many heifers might calve per month during that year. If there are enough heifers available in each month, the ideal intake can be realised. Adjustments to the intake have to be made otherwise (Fig. 1). These adjustments focus on trying to realise the ideal intake as much as possible. In the model two different ways have been defined to adjust intake: (a) without and (b) with changing the length of the rearing period of young stock.

Without changing the length of the rearing period. In case the calculated ideal intake cannot be realised and when the length of the rearing period is not changed, heifers calve in the calendar month they were originally assigned to at the age of either 23, 24 or 25 months. In one or more months a shortage of heifers can be observed. These shortages are eliminated by entering heifers in months with a surplus of heifers. To provide the future availability of heifers calving in months with a shortage, the intake is focused on heifers from surplus months, which on the long term results in the maximum number of calvings in months during which a shortage is observed. This is formulated as the following linear programming problem:

$$\text{Maximize } Z = \sum_{i=1}^{nr_{sp}} \sum_{j=1}^{nr_{st}} a_{ij} x_{ij}, \tag{1}$$

subject to:

(a) $\sum_{i=1}^{nr_{sp}} b_{ij} x_{ij} = \text{shortage}_j$, for all j

(b) $\sum_{j=1}^{nr_{st}} x_{ij} \leq \text{surplus}_i$, for all i

(c) $x_{ij} \geq 0$, for all i and j

In which:

nr_{st} = number of months with shortage of heifers

nr_{sp} = number of months with surplus of heifers

a_{ij} = number of herd calvings at equilibrium in shortage month j when one heifer calves in surplus month i; a_{ij} is obtained from single-month equilibrium herds (see Table 3 in Jalvingh et al., 1993)

x_{ij} = number of heifers calving in surplus month i, to eliminate (partly) shortage in month j

shortage_j = number of heifers short in month j

surplus_i = number of heifers surplus in month i

b_{ij} = scaling factor that assures that ANC is exactly constant on an annual basis and represents the quotient of extra ANC of a heifer calving in shortage month j and extra ANC of a heifer calving in surplus month i (see Table 1).

Especially in the case that shortages of heifers are countered by entering heifers in months at the end of the year, the scaling factor b_{ij} is relatively high, assuring that many heifers enter the herd. This will have a great effect on the number of heifers needed in the following year, since heifers entering during the last months of a year have only little impact on ANC in that particular year, but a great impact on ANC in the following year. To overcome these annual fluctuations in number of heifers entering the herd, the scaling factor b_{ij} is set at 1 in all cases.

With changes in the length of the rearing period. Modification of the length of the rearing period should be interpreted as delaying or advancing the age of first insemination and as a result of this the age at first calving. The initial age at first calving (23, 24 or 25 months) can be increased in the model by 6 months and decreased by 2 months at the maximum. A strategy to change the length of the rearing period is specified by limits for the minimum and maximum age at calving. In the model the maximum age at calving is set at 30 months, and the minimum age at 22 months. The user-defined limits are used to formulate which transitions from surplus months to shortage months are possible, taking into account the initial age at calving. The surplus of heifers from the previous year is also taken into account. At first it is tried to realise the ideal intake by modifying the length of the rearing period of heifers initially calving in surplus months so that they will calve in months with a shortage of heifers. This tuning of surplus heifers to the ideal intake is formulated as a two-step problem in linear programming. In the first step the number of heifers calving in months with a shortage is maximized. In formula:

$$\text{Maximize } Z = \sum_{i=1}^{nr_{sp}} \sum_{j=1}^{nr_{st}} \sum_{l=1}^{3} y_{ijl} \qquad (2)$$

subject to the constraints:

(a) $\sum_{i=1}^{nr_{sp}} \sum_{l=1}^{3} y_{ijl} \leq \text{shortage}_j$, for all j

(b) $\sum_{j=1}^{nr_{st}} y_{ijl} \leq \text{surplus}_{il}$, for all i and l

(c) $y_{ijl} \geq 0$, for all i, j and l

In which:

y_{ijl} = number of heifers changed from calving in age class l (l=1: 23, l=2: 24 and l=3: 25 months) in surplus month i to calving in shortage month j

surplus_{il} = surplus heifers in age class l in surplus month i

In the second step, the priority given to the various changes in the length of the rearing period is taken into account in the objective function. The highest priority is given to little changes in the length of the rearing period. The outcome of the first step is added as an extra constraint to make sure that the maximum number of heifers calving in shortage months will be realised.

In case the ideal intake is not realised by changing the length of the rearing period of available heifers, an additional linear programming problem is formulated to make the actual intake as near as possible to the ideal intake. This is also formulated as a two-step linear programming problem. In the first step the number of calvings on the long term in months during which a shortage of heifers is observed is maximized. This is similar to formula (1), but now includes changes in the length of the rearing period.

TABLE 2

Price correction of a replacement heifer depending on age at calving (Dfl.). Base price of a replacement heifer calving at the age of 24 months is Dfl. 2600

Age at calving (months)								
22	23	24	25	26	27	28	29	30
−45	−33	0	8	16	24	36	48	60

$$\text{Maximize } Z = \sum_{i=1}^{(12-nr_{st})} \sum_{j=1}^{nr_{st}} \sum_{k=1}^{nr_{sp}} \sum_{l=1}^{3} a_{ij} v_{ijkl} \qquad (3)$$

subject to:

(a) $\sum_{i=1}^{(12-nr_{st})} \sum_{k=1}^{nr_{sp}} \sum_{l=1}^{3} v_{ijkl} \leq \text{shortage}_j$, for all j

(b) $\sum_{i=1}^{(12-nr_{st})} \sum_{j=1}^{nr_{st}} v_{ijkl} \leq \text{surplus}_{kl}$, for all k and l

(c) $v_{ijkl} \geq 0$, for all i, j, k and l

In which:

v_{ijkl} = number of heifers calving in month i to overcome shortage in month j; heifer was initially assigned to month of calving k and age class l.

To reduce the number of combinations possible for v_{ijkl}, combinations for which $a_{ij} > a_{kj}$ are allowed only.

In the second step, the priorities for the length of the change in the rearing period are taken into account. The highest priority is given to "no change" in the rearing period. The outcome of the first step is added as an extra constraint to ensure that the maximum number of calvings on the long term will be realised.

The simulation model has been programmed in Turbo Pascal and runs on a personal computer. The linear programming problems are solved by including the routines for the simplex method described by Press et al. (1989).

Changing the age at calving influences the performance in the first lactation. Heifers calving at an older age and higher live weight produce more milk, but need more feed for maintenance and may have more variable costs involved in rearing. Together this leads to the correction of the price of a replacement heifer when not calving at the age of 24 months as given in Table 2.

Analysis

In the basic analysis four strategies will be simulated and compared for one starting situation and one desired situation. In performing the simulation, the basic input variables for reproduction, disposal, milk production, feed intake, slaughter value and prices as described by Jalvingh et al. (1993) in the accompanying paper are used.

In the starting situation a spring calving pattern has been defined, with heifers calving from January to June at a monthly rate of 5, 20, 25, 25, 20 and 5% respectively. The desired pattern includes heifers calving in autumn at similar monthly rates, but now for the months August to January. The herd calving patterns in the starting and desired situation are a result of the heifer calving pattern and the transition probabilities that are used. The heifer calving patterns have been chosen in such a way, that they can be realised by raising and inseminating calves born in the herd. The average herd size is set at 100 cows.

Jalvingh et al. (1993) slightly modified the dynamic programming model of Van Arendonk (1986) to determine the optimum insemination and replacement decisions for individual cows, taking into account seasonal variation in performance and prices. These optimal decisions are used in (a) determining the herd at equilibrium belonging to the desired situation and (b) when following the herd through time to calculate the consequences of one particular strategy. In the starting situation the optimal decisions are used belonging to the situation without seasonal variation in performance and prices.

The four strategies to be compared are presented in Table 3. In strategy I the length of the rearing period is not allowed to change. In the other strategies the length of the rearing period is allowed to change; the minimum and maximum age at calving vary. The herd will be followed over time during a period of 10 years. One year runs from April to March, which is the administrative period for the current EC milk quota system.

The following measure is used to summarize to what extent the realised and desired calving patterns deviate:

$$\sqrt{\sum_{i=1}^{12} (r_i - d_i)^2 / 12}$$

TABLE 3

Overview of strategies that will be compared

Strategy	Length of rearing period	Minimum age at calving	Maximum age at calving
I	not changed	–	–
II	changed	23	25
III	changed	23	27
IV	changed	22	29

in which:
r_i = realised percentage of calvings in month i
d_i = desired percentage of calvings in month i

The economic consequences of the strategies are shown by comparing them with a strategy in which the desired situation equals the starting situation (strategy 0; no change of calving pattern). The strategies are compared for different time periods. The net present value of gross margin per cow per year is calculated by summing the discounted annual values of gross margin per cow per year for the period of consecutive years to which the present value refers. The discount rate is set at $0.96^{1/12}$ per month. Additionally, the net present value is converted into annual equivalent values by using the amortization factor procedure in order to make a good comparison possible at different points in time (Boehlje and Eidman, 1984). Unless stated otherwise, all revenues and costs mentioned in this paper refer to the annualized net present value.

Finally, a sensitivity analysis will be carried out. First, the consequences of an increase in the costs of changing the length of the rearing period is calculated. In case the age at calving deviates from 24 months, Dfl. 30 of extra costs are taken into account per month of deviation. The effects of extra actions taken in changing the calving pattern will be investigated. The extra actions consist of allowing no inseminations of cows in June and July in year 1 to 3, which results in no calvings of cows in March and April. Heifers can still enter the herd in March and April.

RESULTS

Starting and desired situation

In Fig. 2, the heifer and herd calving patterns are presented belonging to the steady state herds in the starting and desired situation. As could be expected, the majority of herd calvings takes place in the same season as the majority of heifer calvings, but there are also cows calving in the less favourable months. In Table 4, the major technical and economic results of the two herds are presented. Gross margin per cow per year is in the desired situation Dfl. 115 higher than in the starting situation. This difference originates mainly from differences in milk revenues due to differences in average milk price premium received per kg of milk and the average milk production per cow. The interval between calving and culling in the desired situation is 16 days longer than in the starting situation, which is due to all voluntary cullings (210 vs. 178 days). This is a result of including seasonal effects in determining the optimal insemination and replacement decisions for individual cows in the desired situation.

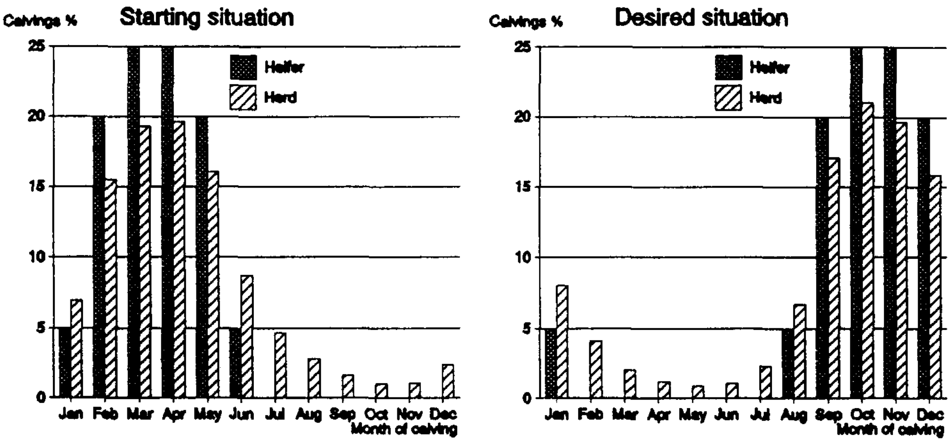

Fig. 2. Calving pattern of heifers and herds in starting situation and desired situation.

TABLE 4

Major technical and economic results of herds belonging to starting situation and desired situation

	Starting situation	Desired situation
Ave number of cows	100.0	100.0
Number of calvings	115.4	114.5
Culling rate herd (%)	31.0	31.9
Interval calving-culling (days)	171	187
Calving interval (days)	371	371
Milk per ave cow (kg)	7072	7128
Ave milk price premium (Dfl/100 kg)	−0.71	0.95
Economic results (Dfl/ave cow)[1]		
Revenues		
milk	5867	6080
calves	400	374
culls	479	508
Costs		
feed	1543	1617
heifers	815	841
Gross margin	4388	4503

[1]Annualized net present value.

Strategies to change calving pattern

For strategy II, the heifer and herd calving patterns are illustrated in Fig. 3, showing the change in calving pattern when going from the starting situation to the desired situation. The desired calving pattern for heifers is realised for the first time in year 9. The herd calving pattern belonging to the desired heifer calving pattern is not realised within 10 years. To what extent the realised calving pattern deviates from the desired calving pattern for all strategies

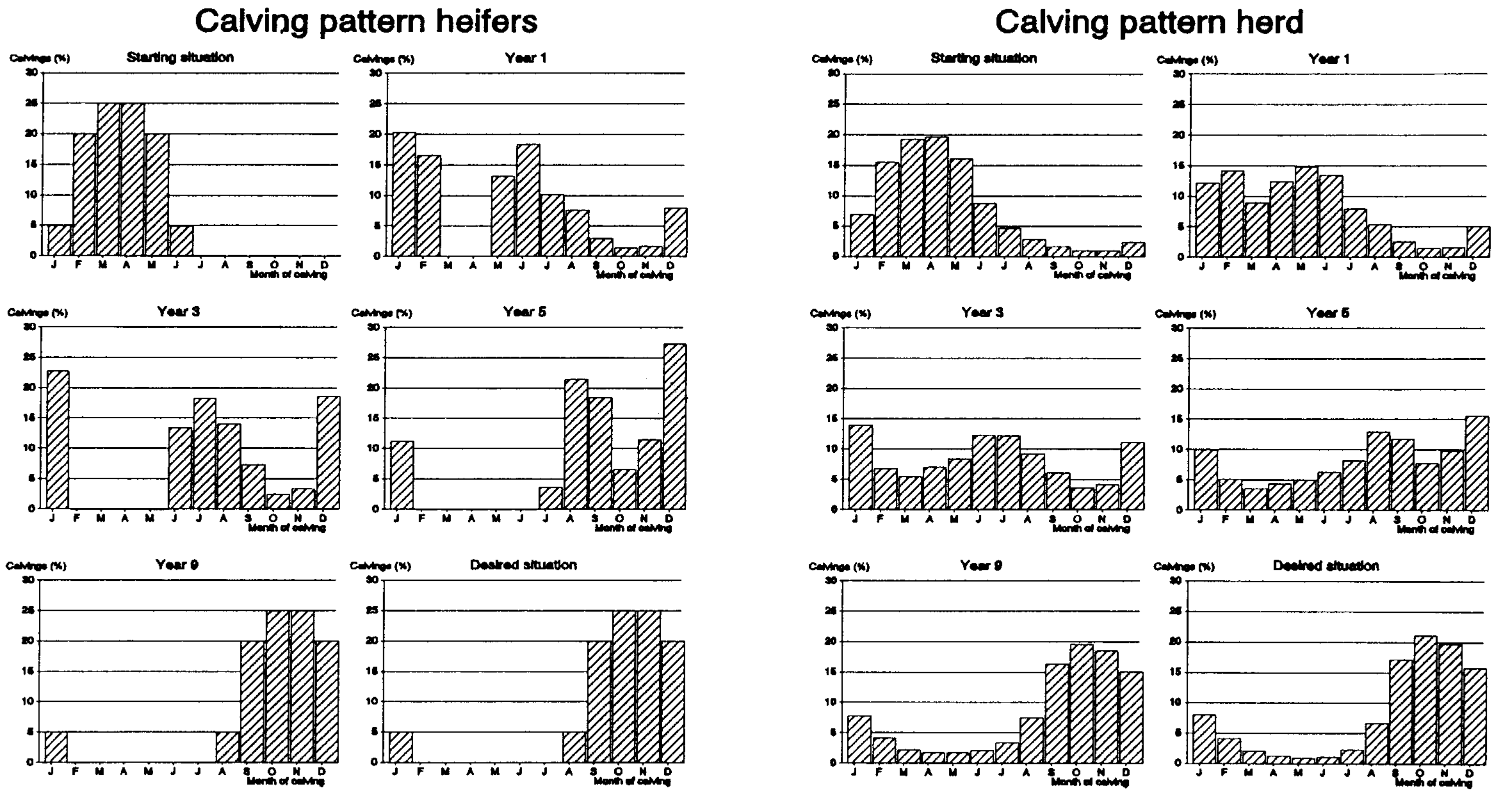

Fig. 3. Heifer and herd calving pattern for starting situation, desired situation and period going from starting situation to desired situation in the case of strategy II.

TABLE 5

Deviation realised heifer and herd calving pattern from desired heifer and corresponding herd calving pattern in time for all strategies and year in which deviation becomes zero

Year	Heifers				Herd			
	I	II	III	IV	I	II	III	IV
0	18.6	18.6	18.6	18.6	23.1	23.1	23.1	23.1
1	15.5	14.9	13.5	4.9	20.0	19.1	17.2	9.5
2	15.4	14.8	13.7	0.0	19.4	18.4	16.5	5.2
3	14.7	13.1	7.0	0.0	18.4	16.1	9.4	3.2
4	14.1	11.3	0.0	0.0	17.5	13.8	3.6	2.0
5	13.0	8.6	0.0	0.0	16.1	10.6	2.2	1.1
6	12.1	6.5	0.0	0.0	14.8	7.8	1.3	0.7
7	11.1	3.7	0.0	0.0	13.5	4.6	0.8	0.3
8	10.2	1.4	0.0	0.0	12.3	2.1	0.4	0.2
9	8.8	0.0	0.0	0.0	10.7	0.9	0.2	0.0
10	7.5	0.0	0.0	0.0	9.1	0.5	0.1	0.0
Deviation zero in yr	17	9	4	2	20	14	11	9

in different years is presented in Table 5. The strategy that is the most flexible in changing the rearing period of young stock (IV) is the first to realise the desired heifer and herd calving patterns. Although the desired heifer calving pattern has already been realised in year 2, it takes several years more before the corresponding herd calving pattern is realised. Strategy I, allowing no change in the length of the rearing period, is the slowest to reach the desired calving pattern. Not until year 17 is the desired heifer calving pattern realised. The corresponding herd calving pattern is already realised 3 years later (Table 5), since the desired heifer calving pattern is approached more gradually than in the other strategies.

Table 6 shows some characteristics for all strategies concerning the replacement heifers that enter the herd in different years. The replacement rate in the first year is about 10% higher than in the starting situation, and gradually declines in the years after. The high increase in replacement rate in the first year is a result of the change in insemination and replacement strategy used. The new strategy focuses on realising calvings in autumn. In the first year many animals do not calve in the desired season, and many of them, therefore, are not inseminated but culled later on. In the first year of strategies II, III, and IV, the rearing period of the majority of heifers entering the herd is changed. This percentage declines later on. The rate by which it declines depends on to what extent the desired heifer calving pattern is realised. In Table 7, the distribution of heifers over age classes in year 1 is presented. The rearing period is lengthened or shortened as much as possible and as much as needed.

TABLE 6

Major characteristics concerning replacement heifers entering the herd in specific years

	Year	Strategy			
		I	II	III	IV
Replacement rate (%)	1	41.6	41.1	40.9	41.6
	2	37.4	36.5	35.1	31.1
	3	37.6	35.6	34.0	34.6
	5	35.9	32.6	31.6	33.5
	9	33.4	31.6	32.1	33.5
Ave age at calving (months)	1	24.0	24.1	25.5	26.3
	2	24.0	24.0	25.4	26.5
	3	24.0	24.1	25.4	24.9
	5	24.0	24.0	24.5	24.0
	9	24.0	24.0	24.0	24.0
Proportion of heifers with length of rearing period changed (%)	1	0.0	62.4	77.5	82.6
	2	0.0	59.9	77.6	78.3
	3	0.0	58.4	63.8	46.2
	5	0.0	42.3	26.0	11.0
	9	0.0	4.2	0.0	0.0

TABLE 7

Distribution of replacement heifers entering the herd in year 1 over age classes for all strategies (%)

Age at calving	Strategy			
	I	II	III	IV
22	–	–	–	16.4
23	25.6	41.9	28.4	11.0
24	49.6	7.8	7.8	7.8
25	24.8	50.3	4.5	3.7
26	–	–	4.1	0.2
27	–	–	55.1	3.6
28	–	–	–	3.7
29	–	–	–	53.6

In Fig. 4, the annualized net present value of gross margin per cow per year is presented for different periods of time and for all strategies. The given values are expressed as the deviation from the annualized net present value for strategy 0 (no change of calving pattern). Annual fluctuations in gross margin per cow per year are a result of annual fluctuations in number of replacement heifers entering the herd. Strategy IV is the most profitable strategy in changing the calving pattern when considered after a few years, and also when

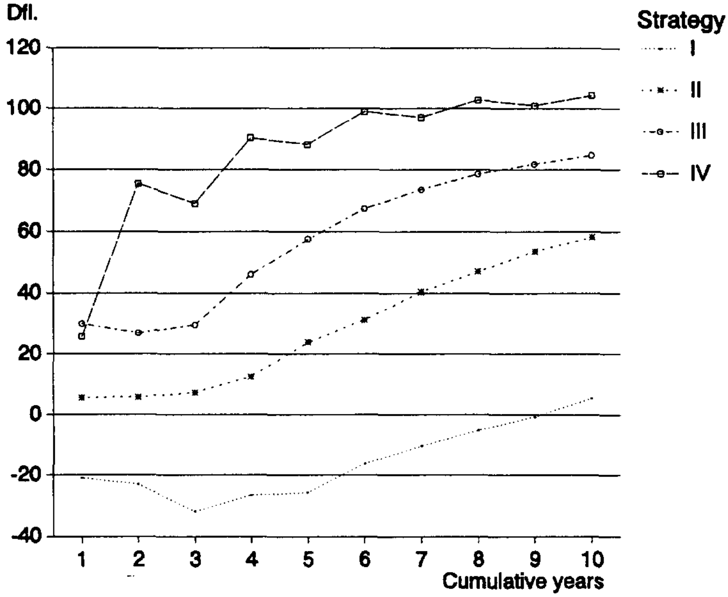

Fig. 4. Annualized net present value of gross margin per cow per year for the respective cumulative years, expressed as deviation from strategy 0.

considered after 10 years. When the number of years considered increase, the benefit per cow per year realised by changing calving pattern also increases, until a certain maximum has been reached. Considering a period of 10 years, an increase in gross margin of Dfl. 105 per cow per year can be realised with strategy IV. In case of strategy I, the benefits amount to only Dfl. 6 per cow per year after 10 years (Fig. 4), while in previous years the costs of changing exceed the benefits. The high increase in replacement costs in the first few years, due to the increase in culling rate, cannot be compensated for by extra milk revenues. It takes more time before heifers calve in months resulting in higher milk revenues. Table 8 presents, for all strategies, more precise information on annualized net present value of revenues and costs in year 1. The milk production per average cow present in the herd in year 1 is approximately 140 (strategy I) to 270 kg (strategy IV) higher than in the starting situation, due to the increase in the culling rate in year 1 (Table 8). The extra cows that are culled, mainly spring calving cows culled in autumn, contribute considerably to milk production in year 1. Since they are replaced by replacement heifers before reaching the period of low production or no production at all (dry period), a reduction in the average length of the lactation and in the average length of the dry period per lactation can be observed. Together with the increase in the total number of calvings, this results in the observed increase in milk production per average cow present in the herd. This increase is temporary; in the following years the milk production is approximately 150

TABLE 8

Results strategy 0 and I to IV for year 1. Results for strategies I to IV are expressed as deviations from strategy 0 (no change in calving interval)

	Strategy				
	0	I	II	III	IV
Milk per ave cow (kg)	7072	+141	+174	+199	+269
Ave milk price premium (Dfl/100 kg)	−0.71	−0.05	+0.08	+0.30	+0.56
Economic results (Dfl/ave cow)[1]					
Revenues					
milk	5867	+104	+138	+176	+245
calf	399	+19	+17	+15	+10
culls	479	+150	+141	+140	+109
Costs					
feed	1543	+10	+18	+24	+44
heifers	815	+284	+273	+276	+295
Gross margin	4388	−21	+6	+30	+26

[1]Annualized net present value.

(strategy I) to 200 kg (strategy IV) lower than in year 1. This can be explained by the reduction in the culling rate and the number of calvings and consequently more cows in the dry period. Also the proportion of younger, less productive animals present in the herd is higher in these years.

Sensitivity analysis

In Fig. 5, the annualized net present value of gross margin per cow per year is presented for all strategies in the case that the costs of changing the length of the rearing period have been increased by Dfl. 30 per month of deviation from 24 months. As could be expected, gross margin decreases, especially the first few years. The highest decrease is found for strategy IV, since in this case the greatest changes in age at calving take place. In year 1, gross margin is decreased by Dfl. 38, and becomes lower than in strategy 0. Considering a period of 10 years, the gross margin decreases by Dfl. 10 per cow per year compared to the basic situation. For strategies I, II and III the gross margin per cow per year is decreased by Dfl. 1, 3, and 7 respectively.

In Fig. 6, the annualized net present value of the gross margin per cow per year is presented for the situation in which, as an additional measure, cows are not inseminated in June and July during the years 1 to 3. In year 1, the gross margin per cow per year is for all strategies higher than in the basic analysis. The increase in replacement rate, from about 41% to 47%, results in higher replacement costs. This is, however, outweighed by higher milk revenues, since the increase in the culling rate results in a higher increase in milk production per cow. When considering 2 years, the reduction in the net pres-

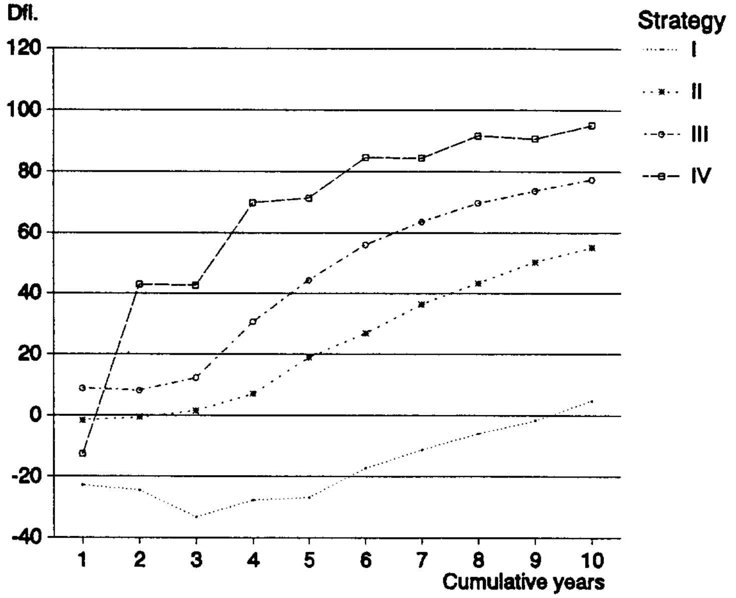

Fig. 5. Annualized net present value of gross margin per cow per year for the respective cumulative years, expressed as deviation from strategy 0. Costs of changing the length of the rearing period have been increased.

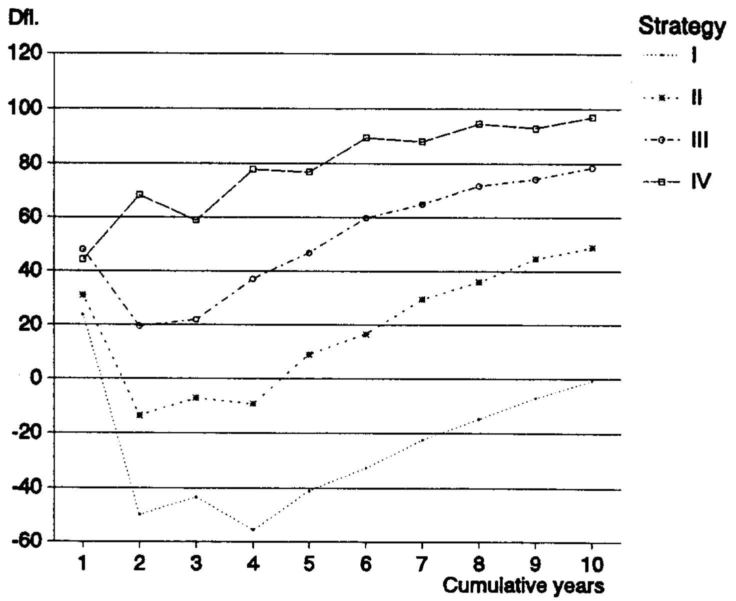

Fig. 6. Annualized net present value of gross margin per cow per year for the respective cumulative years, expressed as deviation from strategy 0. In years 1 to 3 no inseminations are allowed in June and July.

ent value in the case of strategies I, II and III is larger than in the basic analysis, because of lower milk revenues and higher replacement costs. The reduction in milk revenues can be explained by a higher decrease in milk production in both year 2 and the following years (300 (I) to 390 kg (III)) compared to the basic analysis, which is a result of the higher proportion of younger cows in the herd. Since the replacement rate in year 1 is very high, more heifers enter the herd in less desirable months, resulting in additional cullings and higher replacement costs in year 2 compared to the basic analysis. Over a period of 10 years, the gross margin is decreased for all strategies by approximately Dfl. 7 per cow per year. "No inseminations in certain months of the year" as an additional measure in changing calving pattern, therefore, does not turn out to be economically attractive.

DISCUSSION AND CONCLUSIONS

The modelling approach presented in this paper is able to make both static and dynamic comparisons of herd calving patterns. Calculations so far on the profitability of changing the calving pattern were restricted to a comparison of the profitability of the starting and the desired situation (Mandersloot et al., 1987; Wunder and Orth, 1989), combined with an enumeration of costs of individual measures (Strandberg and Oltenacu, 1989; Schmidt, 1989). No attention was paid to the consequences of actually changing the calving pattern of the herd. The results of the current study show the importance of going beyond such a static comparison of calving patterns. The maximum possible profit to be obtained depends on the difference in profitability of the starting and desired situation. But, the profit that will actually be realised when changing the calving pattern, depends on the strategy applied and on the moment in time the profitability is considered. In the current study a spring calving herd is changed into an autumn calving herd by strategies focusing on the farm's intake of replacement heifers. The strategy that is able to realise this increase fastest turns out to be the most profitable one to change calving pattern. Each strategy approaches a certain maximum profit per cow per year but this is still lower than the difference in profitability of the starting and desired situation. The maximum value that can be realised with a certain strategy, depends mainly on the results obtained in the first few years.

The difference in gross margin between the starting and desired situation used in this paper amounts to Dfl. 115 per cow per year. In using strategy IV, the maximum profit to be realised is Dfl. 105 per cow per year. In the decision of farmers to actually change calving pattern, the level of this profit will be decisive, together with the amount of effort it will take to apply the strategy. The level of the total profit to be obtained in the basic analysis in this paper (Dfl. 115 per cow per year), can considered to be rather high when compared to other measures farmers can apply. Van Arendonk (1987) calculated that applying the optimal insemination and replacement decisions of individual animals lead to a Dfl. 46 higher annual income per cow than in the situation where all cows are inseminated and kept if they conceived. If the optimal decisions were compared with optimal decisions based on the expected milk revenues only, the profit was Dfl. 13 per cow. When all farmers decide to change the calving pattern, the seasonal differences in several prices may change, since the seasonal supply will then have changed. The modelling approach presented in this paper, can be used to determine the consequences of different price scenarios on the profitability of different calving patterns and on the profitability of actually changing the calving pattern. If seasonal variation in prices of milk, calves, heifers and slaughter value will disappear completely after a few years, the maximum profit to be realised will be Dfl. 50 per cow per year, which is considerably less than in the basic situation. However, it is still profitable to change the calving pattern to an autumn calving herd.

The strategies are compared for a herd with a good reproductive performance (average calving interval of 371 days). The modelling approach can also be used to simulate herds with poor reproductive performance. In case of the same starting and desired heifer calving patterns as in the basic analysis, the resulting herd calving pattern will be spread more widely. This means that differences in profitability between the starting and the desired situation will be smaller (Jalvingh et al., 1993). Moreover, these herds will have more difficulties in realising a heifer calving pattern concentrated in a few months, since not enough calves will be available in these months, and, therefore, changes in the rearing period have to be made continuously. Thus, more profit can be obtained by improving the reproductive performance before changing the calving pattern.

The strategies have been compared for a situation in which the average number of cows present in the herd is kept constant on an annual basis. The method which has been developed is flexible enough to carry out calculations for a situation in which, for instance, the annual milk production of the herd is kept constant or is even decreasing over time (quota system). Additional calculations have been carried out for the situation in which annual milk production of the herd is kept constant. The quotum is set equal to the annual milk production in the starting situation. At the start of each year, calculations are carried out to determine the intake of heifers resulting in a constant annual milk production of the herd, similar to the approach used in the case of constant herd size (Fig. 1). Calculations show the same results as in the case of a constant annual herd size, except for years 1 and 2. Gross margin in year 1 is for all strategies approximately Dfl. 180 higher than in year 1 of that same strategy in the basic analysis. Due to the high increase in milk production per cow in year 1, part of the culled cows is not replaced by heifers, resulting in a smaller increase in replacement costs. In year 2 the milk production per cow is much lower, combined with the gap between the culling rate and the replacement rate in year 1, this results in a high increase in the replacement rate and costs in year 2. The gross margin per cow per year considered after 2 years is at the same level as in the basic analysis.

Starting point in defining the desired situation is the desired heifer calving pattern. However, the formulation of a desired herd calving pattern fits better in the farmers' perception, and is, therefore, more suitable for use in the field. In a future paper a method will be described for determining the farm-specific optimum herd calving pattern using linear programming and the technical and economic results of single-month equilibrium herds. In determining the farm-specific optimum calving pattern, various restrictions at herd level, such as milk quota, maximum herd size and labour supply, can be taken into account. After determining this optimum, the model described in the present paper can be used to compare different strategies to change the current calving pattern to the farm-specific optimum calving pattern.

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REFERENCES

Boehlje, M.D. and Eidman, V.R., 1984. Farm Management. John Wiley & Sons, New York, 806 pp.

Jalvingh, A.W., Van Arendonk, J.A.M. and Dijkhuizen, A.A., 1993. Dynamic probabilistic simulation of dairy herd management practices. I. Model description and outcome of different seasonal calving patterns. Livest. Prod. Sci., 37: 107–131.

Mandersloot, F., Hengeveld, A.G. and Werkgroep WZM, 1987. Gevolgen van verschuivingen in afkalfpatroon. Technische en bedrijfseconomische resultaten van de studie Winter/Zomermelk. Publikatie nr. 45. Proefstation voor de Rundveehouderij, Schapenhouderij en Paardenhouderij, Lelystad, 55 pp. (in Dutch)

Press, W.H., Flannery, B.P., Teukolsky, S.A. and Vetterling, W.T., 1989. Numerical Recipes in Pascal. The art of scientific computing. Cambridge University Press, Cambridge, 759 pp.

Schmidt, G.H., 1989. Effect of length of calving intervals on income over feed and variable costs. J. Dairy Sci., 72: 1605–1611.

Strandberg, E. and Oltenacu, P.A., 1989. Economic consequences of different calving intervals. Acta Agric. Scand., 39: 407–420.

Van Arendonk, J.A.M., 1986. Studies on the replacement policies in dairy cattle. IV. Influence of seasonal variation in performance and prices. Livest. Prod. Sci., 14: 15–28.

Van Arendonk, J.A.M., 1987. Contribution of variables to the optimum policy for insemination and replacement of dairy cows. Zeitschrift für Tierzüchtung und Züchtungsbiologie, 104: 35–43.

Wunder, W.W. and Orth, R.L., 1989. Economic returns from changing calving month to increase milk produced in the fall. J. Dairy Sci., 72 (Suppl. I): 456.

RESUME

Jalvingh, A.W., van Arendonk, J.A.M., Dijkhuizen, A.A. and Renkema, J.A., 1993. Simulation dynamique de méthodes de conduite des troupeaux laitiers II Comparaison de stratégies visant à changer les dates de vêlage. *Livest. Prod. Sci.*, 37: 133–152 (en anglais).

Un modèle de simulation dynamique a été utilisé pour la comparaison de différentes stratégies en vue de changer les dates de vêlage d'un troupeau. L'approche des chaines de Markov a été utilisée pour simuler la dynamique du troupeau. Les stratégies de changement des dates de vêlage ont reposé sur le rôle possible des génisses de renouvellement en faisant varier l'âge au premier vêlage. Une méthode de programmation linéaire en vue d'ajuster les génisses de remplacement au système de vèlage désiré. On a ainsi cherché à faire passer la saison de vèlage du printemps à l'automne. La différence de marge brute par vache et par an entre les deux situations est de 115 florins par vaches. La stratégie la plus efficace est celle qui permet de larges variations de l'âge au premier vêlage. La saison de vêlage désirée est obtenue en 2 ans pour les génisses et en 9 ans pour l'ensemble du troupeau. Sur 10 ans, on gagne ainsi 105 florins par vache et par an. En ne modifiant pas l'âge au premier vêlage, on n'obtient que 6 florins. Il n'est pas économiquement intéressant d'exclure l'insémination pendant certaines périodes de l'année.

KURZFASSUNG

Jalvingh, A.W., Van Arendonk, J.A.M., Dijkhuizen, A.A. und Renkema, J.A., 1993. Dynamische, stochastische Simulation von Managementsrategien in Milchrindherden. II. Vergleich von Strategien zur Veränderung der Abkalbezeiten einer Herde. *Livest. Prod. Sci.*, 37: 133–152 (auf englisch).

Ein dynamisches, stochastisches SImulationsmodell wurde weiterntwickelt und für den Vergleich von unterschiedlichen Strategien zur Veränderung der Abkalbezeiten einer Herde verwendet. Die Markow-Ketten-Theorie wurde genutzt, um die Herdendynamik zu simulieren. Die Strategien zur Änderung der Kalbezeiten, die verglichen wurden, konzentrierten sich auf das Einkommen der Farmer aus dem Verkauf von Reproduktionsfärsen, wobei eine bestimmte Variation des Erstkalbens zugelassen wurde. Es wurde eine Methode unter Nutzung der linearen Programmierung entwickelt, die es erlaubt, die verfügbaren Reproduktionsfärsen zu einer erwünschten Abkalbezeit der Färsen einzustellen. In der Basisanalyse wechselte die Herde von Frühjahrs- zur Herbstabkalbung. Die Differenz im Gesamteinkommen pro Kuh und Jahr zwischen der Ausgangs- und gewünschten Situation betrug 115 hfl. Die Strategie, die die größte Variation im Erstkalbealter zuläßt, bewirkt die schnellste Veränderung in der Kalbezeit. 9 Jahre sind notwendig, um die gewünschte Herdenkalbezeit zu erreichen, während die angestrebte Kalbezeit der Färsen bereits nach 2 Jahren erreicht ist. Diese Strategie ist auch die wirtschaftlichste. Über eine Periode von 10 Jahren ergibt diese Strategie 105 hfl je Kuh und Jahr. Wenn die Strategie am Beginn keine Änderung des Erstkalbealters zuläßt, beträgt der Zuwachs nach 10 Jahren nur 6 hfl je Kuh und Jahr, während in den Jahren zuvor die Kosten der Veränderung den Nutzen überschritten. Eine zusätzliche Maßnahme, die vorsieht, daß in den ersten Jahren in bestimmten Monaten keine Kühe besamt werden, erwies sich nicht als wirschaftlich attraktiv.