ECONOMIC DECISION MAKING FOR REPRODUCTION

Victor E. Cabrera and Julio O. Giordano
University of Wisconsin, Madison

INTRODUCTION

Reproductive efficiency plays an important role in the economics of dairy farming (Jalvingh, 1993; Olynk and Wolf, 2009; Lima et al., 2010). A direct relationship between reproductive performance and profitability has long been recognized (Britt, 1985); consequently improving reproductive efficiency will improve profitability (DeLorenzo et al., 1992; Meadows et al., 2005) because suboptimal reproductive efficiency is costly (Groenendaal et al., 2004; Meadows et al., 2005; De Vries, 2006).

Economic evaluation of reproductive programs performed by dairy farmers is extremely difficult (Fricke et al., 2008). Nonetheless, this is a frequent question from producers, dairy consultants, Extension professionals, and veterinarians. The answer is complex because a number of factors interact dynamically. For instance, the efficiency of the reproductive program determines:

- The lactation length and hence the milk production value;
- The probability of culling and death and hence the cost of culling and death;
- The reproductive protocols and hence the cost of the reproductive program; and
- The timing of calving and hence the income because of calves.

These integrated factors are the most important economic factors in any dairy farm business.

Several methods could be used to assess the value of reproductive programs such as: partial cash flow (Meadows et al., 2005; Giordano et al., 2010), marginal net revenue (Groenendaal et al., 2004), or dynamic programming (De Vries, 2006). However, because of its complexity, it is critical to use a methodology that is inclusive and practical. The methodology needs to be inclusive to account for all the complex factors affecting the economics of the dairy in an integrated and dynamic way. The methodology also needs to be practical and feasible in order to lead to the creation of user-friendly decision making tools. Farm management and market conditions are permanently changing and consequently re-evaluations of reproductive programs on a continuous basis are warranted.

To date, models of dairy herd profitability and reproductive program evaluations have used monthly (Cabrera, 2010; Kalantari et al., 2010) or weekly (De Vries, 2004; 2006) time increments. Consequently, the evaluated reproductive programs were forced to adjust to these time spans compromising the sensitivity of the model to the time elapsed between successive reproductive services. Markov-chains methodology (St-Pierre and Jones, 2001; Eicker and Fetrow, 2003; Cabrera et al., 2006), that is the baseline structure of dynamic programming, could be used as a solid framework to assess the economic value of distinct reproductive programs on dairy farms. Markov-chains can accommodate daily time spans; and consequently be more responsive to the changes in herd dynamics resulting from the application of pre-defined reproductive programs consisting of timed artificial insemination (**TAI**), estrous detection, or a combination of both reproductive management strategies.

The specific aim of this paper was twofold:

1. To describe the development of a daily dairy herd Markov-chain model and
2. To evaluate 3 different reproductive management programs for dairy herds using the developed model.

MATERIALS AND METHODS

A dairy herd was represented by daily Markov-chains of events. Every cow in the model followed daily probabilistic events of aging, culling, mortality, becoming pregnant, having an abortion, calving, and starting the next lactation. A defined lactation curve determined the milk production depending on lactation number, days in milk (**DIM**), and reproductive status. Cows being culled and dying were replaced the next day, so the herd population remained constant (Meadows et al., 2005; De Vries, 2006). A large algorithm that included more than 2.5 million interacting equations solved the problem by iterations that caused the herd population to reach a *steady state*. Steady state of the herd population occurred when the number of cows in each specific state (lactation, DIM, reproductive status) did not change from one iteration (stage or time) to the next.

Transition probabilities defined the probabilities of a group of cows moving from one state to the next. For instance, a nonpregnant cow could become pregnant, be culled, or die and a pregnant cow could abort, be culled, die, or calve at the end of gestation. These events occurred daily for each cow in the herd. Transition matrices of culling rates, mortality rates, and reproductive events were defined as daily probabilities following the model dimensions.

The value of a reproductive program was calculated every day for each cow in the herd as the sum of 5 factors: milk income over feed cost, culling cost, mortality cost, income from newborns (calves), and cost of the reproductive programs.

The matrix was defined by 1020 DIM x 282 d in gestation x 9 lactations. The dimensions of the model allowed for a cow to become pregnant any time after calving until DIM = 738; therefore the last possible DIM of a cow for calving was 738 + 282 = 1020. Cows very rarely calve after 600 or 700 DIM, but the model had those large dimensions in order to include all possibilities. The dimensions of the model included 1.87 million possible cow states. An economic value, using the 5 factors described above, was calculated for each possible cow state. Once the herd population reached steady state, the value of the studied reproductive program was calculated as the sum product of the vector's value of the reproductive program in each cow state times the proportion of cows in each state. Different reproductive programs yield different herd structures and consequently different economic values. A comprehensive analysis needs to compare reproductive programs when the herd population reaches steady state.

Herd Structure

The herd structure was defined by:

1. The reproductive program that determined the probability of a cow becoming pregnant,
2. The probability of involuntary culling,
3. The probability of death, and
4. The probability of abortion.

Also, the herd structure was impacted by voluntary culling due to reproductive failure based upon the interaction of a cow's milk yield and a pre-defined cut-off DIM for breeding that was specific for the reproductive program. All these parameters interacted in a daily time span for several thousand iterations until they reached steady state. The probability that a cow might become pregnant, be culled, die, or abort were lactation specific and depended upon the cow's pregnancy status.

Reproductive Program

The model could accommodate reproductive programs with either or both components (1) TAI and (2) estrous detection or breeding after observed estrus (**HD**). For a pure TAI program, the voluntary waiting period (**VWP**) defined the DIM for the first TAI service. For a pure HD program or a program combining HD and TAI, the VWP defined the DIM at which cows in estrus were eligible to be detected and inseminated. For a TAI program, the synchronization protocol started some time before the end of the VWP with the administration of hormones. Next, after completion of a synchronization of ovulation protocol, the first TAI occurred at the end of the VWP. For those cows failing to conceive, resynchronizations for second and subsequent services followed; and cows received AI at a defined inter-breeding interval (**IBI**).

The daily probability of pregnancy depended on the reproductive program. For pure TAI programs, it depended on the conception rate (**CR**) that is usually different for first service than for resynchronization; and on the IBI resulting from the application of the different resynchronization programs. For a pure HD program the daily probability of pregnancy depended upon the HD rate (service rate), the probability of pregnancy after each service (CR), and on the average duration of the cow's estrous cycle, which determined the IBI. When a program combined TAI with HD, cows were available to be bred by HD. Those cows not observed in estrus completed the synchronization protocol and were submitted for TAI. On the day of TAI, no insemination after HD occurred.

All open cows in a herd had a probability of becoming pregnant any day between the VWP and the cut-off DIM for breeding, which was the time when the HD or TAI services stopped. The cut-off DIM to cease reproductive services was defined as a particular DIM (e.g., 300 DIM) depending on the reproductive program. Cows after the cut-off DIM and producing a certain amount of milk higher than a defined threshold (e.g., 27 kg/d) were labeled as *do not breed* (**DNB**) and remained in the herd as long as their milk production was above the threshold. When the milk production decreased below the threshold, the cow was removed for reproductive failure (voluntarily culled) and replaced (Figure 1). Replacement animals were available when necessary and entered the herd just after first calving.

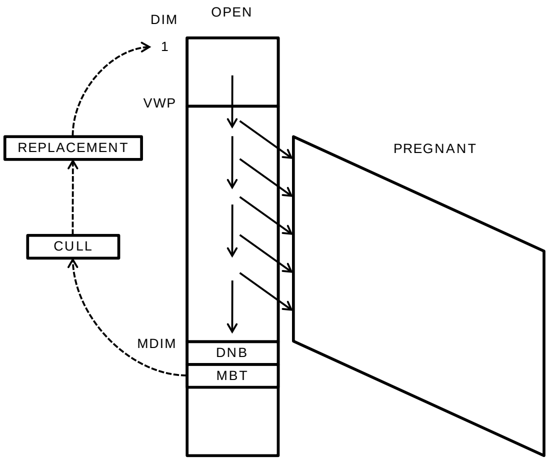


Figure 1. Graphic representation of the breeding process in the Markov-chain structure for one parity. DIM = days in milk (d), VWP = voluntary waiting period (d), MDIM = cut-off DIM for breeding (d), DNB = do not breed, MBT = milk below threshold

Probability of Involuntary Culling and Death

A cow in any state had a probability of involuntary culling or death for any unforeseen reason. Daily probabilities of culling and death were defined for the transition matrices of lactation (1 to 9), open cows (1 to 738 DIM), and pregnant cows (1 to 282 d in pregnancy). The number of culled and dead cows in 1 d was calculated by the multiplication of the vectors number of cows in each state times the probability of culling or death. The difference, cows not culled or dead, moved to the next stage in the dimensions of the model. All culled and dead cows were replaced the next day. Replacement cows entered the herd just after first calving (Figure 2). Cows calving in last lactation (lactation 9) were assumed to be at the end of their productive life and they were culled and replaced (St Pierre and Jones, 2001; Cabrera, 2010). The implication of the latter assumption is minimal, because < 0.1 % of the herd population will ever reach those states.

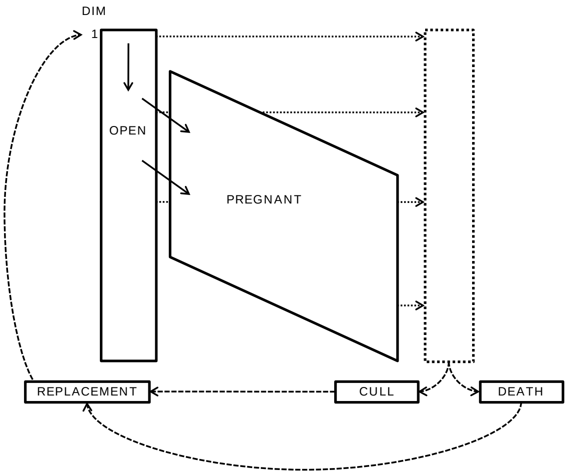


Figure 2. Graphic representation of the involuntary culling and death process in the Markov-chain structure for one parity. DIM = days in milk

Probability of Abortion

Pregnant cows had a daily probability of abortion. Daily probabilities of abortion were defined for the transition matrix of pregnancy (1 to 282 d). The number of cows that aborted in 1 d was calculated by multiplying the vectors number of pregnant cows in each pregnancy state multiplied by the probability of abortion. Cows aborting joined the open cows in the next stage (Figure 3).

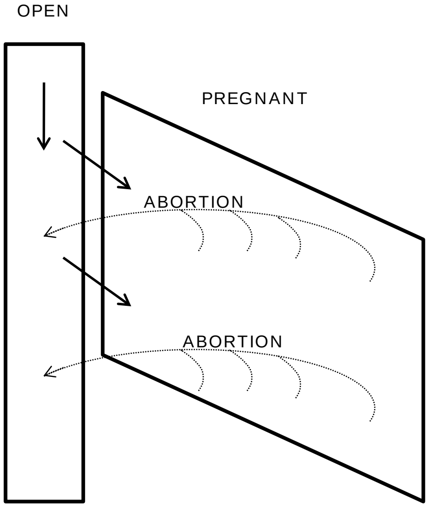


Figure 3. Graphic representation of the abortion process in the Markov-chain structure for one parity.

Experiment

Reproductive Programs

Three reproductive programs were compared (Table 1). Program 1 used HD for all services and had a 50 d VWP. Program 2 relied entirely on TAI to perform all breedings and had a 72 d VWP coincident with the time of the first TAI service. The third program utilized a combination of HD and TAI for all breedings with a 50 d VWP for HD as in Program 1 and 1st TAI occurring at 72 DIM as in Program 2. For programs 2 and 3, cows were synchronized with Presynch-Ovsynch to receive their first postpartum AI. In Program 3 cows observed in estrus after the second $PGF_{2\alpha}$ of Presynch, which coincided with the end of the VWP, were AI. Only those cows not observed in estrus completed the Ovsynch part of Presynch-Ovsynch. In programs 2 and 3 cows failing to conceive to 1st TAI were submitted to second and subsequent TAI services after resynchronization of ovulation with D32 Resynch resulting in an IBI of 42 d. Program 3 performed HD to breed cows failing to conceive in between TAI services, and only those cows not observed in estrus and AI, continued to receive Resynch. All programs had a dry period of 60 d and a cut-off DIM for breeding of 330 d. Cows in all programs were labeled as DNB when they were open, had more than 330 DIM, and were producing over 27 kg/d. Although the model can accommodate lactation-specific reproductive programs, the current analysis used reproductive parameters that were the same across all 9 lactations.

Milk Production

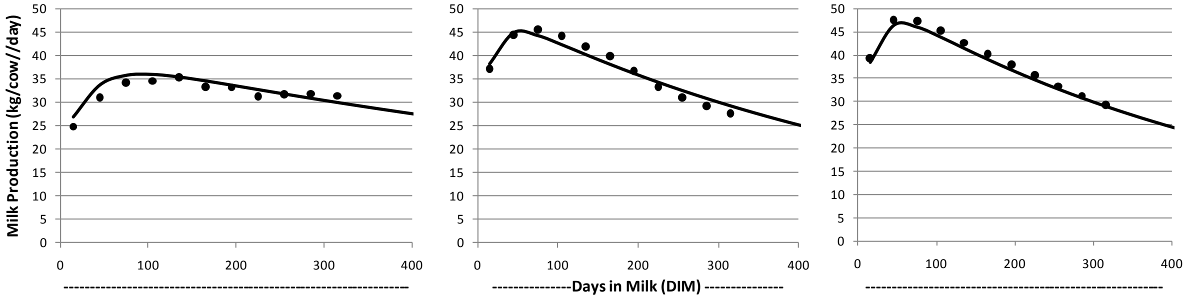
The MilkBot model (Ehrlich, 2009) was used to estimate lactation curves (Equation 1). The MilkBot model predicts milk production (**MP**) per DIM based on 4 parameters: scale (a), ramp (b), offset (c), and decay (d).

$$MP_{DIM} = a * \left(1 - \frac{e^{\left(\frac{c-DIM}{b}\right)}}{2} \right) * e^{-d*DIM} \qquad [1]$$

Table 1. Characteristics of studied reproductive programs

	Program 1	**Program 2**	**Program 3**
Type of Program	HD[1]	100 % TAI[2]	HD + TAI
Name of program: 1st service	Estrous Detection	Presynch-Ovsynch	Presynch-Ovsynch
Name of program: 2nd + service	Estrous Detection	D32 Resynch	D32 Resynch
IBI[3] (d)	NA[4]	42	42
Bred at estrus before 1st TAI (%)	NA	0	60
CR[5] bred at estrus before 1st TAI (%)	NA	0	28
Bred at estrus after 1st TAI (%)	NA	0	60
CR bred at estrus after 1st TAI (%)	NA	0	28
CR 1st Service TAI (%)	NA	42	32
CR 2nd + Service TAI (%)	NA	30	28
HD rate 1st AI (%)	50	NA	NA
CR 1st AI (%)	30	NA	NA
HD rate ≥ 2nd AI (%)	50	NA	NA
CR ≥ 2nd AI (%)	28	NA	NA

[1] HD = Estrous detection or estrous breeding at observed estrus
[2] TAI = Timed artificial insemination
[3] IBI = Interbreeding interval for subsequent TAI
[4] NA = Not applicable
[5] CR = Conception rate



First lactation **Second lactation** **Third lactation**

Figure 4. Observed (dots) and predicted (solid line) milk production (with the fitted MilkBot model) for first, second, and third lactation cows

Observed milk production records were collected from a large commercial Holstein herd in Wisconsin. A fitting algorithm (non-linear optimization) was used to find the best values for each one of the MilkBot parameters. The fitting algorithm minimized the residuals between observed (dairy farm records) and predicted (MilkBot model) data points (Figure 4).

A factor for milk production depression because of gestation was based on De Vries (2004) that indicated that MP would be reduced by 5, 10, and 15 % in months of gestation 5, 6, and 7, respectively. These values were converted to daily factors to be incorporated in the model described here.

Dry Matter Intake

The DMI was a function of the body weight (**BW**) and the MP as reported by Van de Haar et al. (1992):

$$DMI_{DIM} = 2\ \%*BW + 0.3*FCM \text{ and } FCM = 4\ \%*MP_{DMI} + 15*FAT; \qquad [2]$$

where **FCM** was fat corrected milk and **FAT** was milk butterfat content. The BW was assumed to be 1400 lb and the FAT 3.5 %.

Probability of Involuntary Culling and Death

Hazard risks for culling and death were based on De Vries et al. (2010) who reported a greater risk of cows leaving the herd in early lactation, late lactation, and in later parities. Mortality rates were calculated as a proportion (17 %) of these hazard risks according to AgSource Cooperative Services benchmark data (AgSource DHI Cooperative Services, Revised April 09, 2010). Therefore, the model included a daily hazard risk for any cow depending on DIM and parity (parities 1 to 5 and ≥ 6). In addition, the model distinguished hazard risks for open and pregnant cows. The hazard risks for pregnant cows were set at 25 % of the hazard risks of open cows (De Vries et al., 2010). Probability of involuntary culling and death were summarized in daily vectors with the dimensions of the model described here.

Probability of Abortion

Abortion rates were obtained from De Vries (2006), which indicated a probability of 3.5, 2.5, 1.5., 0.5, 0.25, 0.1, and 0.1 % abortion by month 2 to 8 of gestation, respectively. These probabilities were converted to daily abortion risks to be incorporated in the current model.

Table 2. MilkBot parameters used to define lactation curves

MilkBot Parameter	First Lactation	Second Lactation	≥Third Lactation
(a) Scale (kg/cow/d)	40.67	51.00	54.43
(b) Ramp	34.19	18.99	20.83
(c) Offset	0.66	0.35	2.21
(d) Decay	0.00097	0.00177	0.00200

Economic Variables

Price of Milk, Feed, Calves, Replacement, and Salvage Value

Input prices for the model included: $15/cwt milk, $10/cwt feed (dry matter), $300/calf, $1,400/heifer replacement, and $500/cow salvage value.

The value of the reproductive program was calculated daily for each cow state defined in the model and was the product of the proportion of cows in each specific state and the aggregation of the 5 factors previously defined: income over feed cost, culling cost, mortality cost, income from newborn, and reproductive program cost.

The income over feed cost was the difference between the value of the milk and the value of the feed. The culling cost (voluntary and involuntary) was defined as: salvage value – heifer replacement cost + value of the calf (coming with the heifer replacement).

There was no salvage value when a cow died; therefore the death cost was higher than the replacement cost and calculated as: – heifer replacement cost + the value of the calf (coming with heifer replacement).

The income from a new born was the value of a calf, assuming 46.7 % heifer calves (Silva del Rio et al., 2007) calculated at $300.

Reproductive Program Cost

Each reproductive program cost was calculated for a herd with similar characteristics to the one used to obtain the lactation curves. These costs were the aggregation of 4 factors: hormones, labor, artificial insemination (**AI**), and pregnancy diagnosis. The cost of labor included estrous detection (for programs using breeding at estrus) or hormone administration (for programs using TAI). The cost of a 1st service TAI breeding with Presynch-Ovsynch including labor, hormones, pregnancy diagnosis, and TAI was estimated at $30.23/cow (Table 3). The cost of a resynchronized breeding with D32 Resynch including labor, hormones, pregnancy diagnosis, and TAI was estimated at $23.73/cow. The cost of the HD program including labor, AI, and pregnancy diagnosis was estimated at $17.11/cow. Pregnancy diagnosis included the specific labor cost to perform the pregnancy diagnosis after AI. Artificial insemination costs included the cost of the unit of semen and the labor involved in performing the AI. The cost of AI ($10) and pregnancy diagnosis ($6.23) were the same for all programs.

Analysis

Each reproductive program detailed in Table 1 was defined in the model. The model was run until it reached steady state. The solution required around 6000 iterations and took several hours of computational time (between 8 and 10 h). For each run, the value of the reproductive program along with herd statistics were collected, summarized, and discussed.

RESULTS

Reproductive Program 2 (100 % TAI), Presynch-Ovsynch followed by D32 Resynch without HD, had the greatest value of $1993.35/cow/yr and reproductive Program 1, 100 % HD, had the lowest value of $1976.30 (Table 4); a difference of $17.05/cow/yr.

Table 3. Estimated reproductive program costs

Reproductive Program	**Hormones**	**Labor Cost**[1]	**Total Cost**[2]
	-------------------------	($/cow)	--------------------------
Presynch-Ovsynch	10.50	3.50	30.23
D32 Resynch	5.50	2.00	23.73
Breeding at estrus	---	0.88	17.11

[1] Labor cost included hormone administration for Presynch-Ovsynch, D32 Resynch, and estrous detection for breeding at estrus program.

[2] Total cost included $10 per AI semen unit with labor for AI, and $6.23 of labor to perform pregnancy diagnosis

Table 4. Economic value of studied reproductive programs

	Program 1	**Program 2**	**Program 3**
Type of program	HD Only	TAI Only	HD + TAI
Name of program:1st service	Estrous Detection	Presynch-Ovsynch	Presynch-Ovsynch
Name of program: 2nd service	Estrous Detection	D32 Resynch	D32 Resynch
Milk income over feed cost ($/cow/yr)	2003.91	1994.04	1999.98
Culling and mortality cost ($/cow/yr)	-170.86	-152.32	-162.94
Reproductive program cost ($/cow/yr)	-47.17	-66.89	-50.64
Income from newborn ($/cow/yr)	190.42	218.52	204.35
Value of reproductive program ($/cow/yr)	1976.30	1993.35	1990.75
Value over HD Only ($/1000-cow herd/yr)	---	17,050	14,450

[1] TAI = Timed artificial insemination
[2] HD = Estrous detection or breeding after observed estrus

Reproductive Programs 2 (100 % TAI) and 3 (combination of TAI with HD) outperformed reproductive Program 1 (100 % HD). The difference between reproductive programs 2 and 3 (which only differed in the use of HD by Program 3) was $2.60/cow/yr in favor of reproductive Program 2, a substantially smaller difference than the difference between Program 2 and Program 1. Lastly, the difference between reproductive Programs 3 and 1 (which differed in the use of TAI by Program 3), was $14.45/cow/yr in favor of reproductive Program 3.

Comparing the different components of the value of a reproductive program, the greatest milk income over feed cost ($2003.91/cow/yr) was achieved by Program 1, 100 % HD, which also had the greatest cost of culling and mortality (-$170.86/cow/yr), the lowest reproductive program cost (-$47.17/cow/yr), and the lowest income from calves ($190.42/cow/yr; Table 4). Program 2, 100 % TAI, had the lowest income over feed cost ($1994.04/cow/yr), the lowest culling and mortality cost (-$152.32/cow/yr), the greatest reproductive program cost (-$66.89), and the greatest income from new born ($218.52/cow/yr). The combined TAI with HD program (Program 3) had costs and income values in between the other programs.

The proportion of first parity cows in the herd ranged from 33.56 % (Program 2) to 41.36 % (Program 1; Table 5). The TAI program not using HD (Program 2) had the lowest proportion of first parity cows; whereas the 100 % HD program (Program 1) had the greatest. Programs using TAI had a lower proportion of cows in the first 2 parities than the 100 % HD program. Conversely, Program 1 (100 % HD) had a lower proportion of the cow population for later parities than programs 2 and 3.

Between 75.70 (Program 2) and 83.35 % (Program 1) of the herd population was within the first 3 parities and between 93.87 (Program 2) and 96.74 % (Program 1) of the herd population was within the first 5 parities. Furthermore, only 0.09 (Program 1), 0.25 (Program 2), and 0.14 % (Program 3) of the herd population reached parity 9.

The proportion of pregnant cows in a day in the herd varied between 45.33 (Program 1) and 52.45 % (Program 2). The 100 % TAI program (Program 2) had a higher proportion of pregnant cows than the programs using HD.

The average herd DO varied among reproductive programs. The 100 % TAI program (Program 2) had the lowest DO (130 d) and the all HD had the largest DO (147 d). The combined TAI and HD program (Program 3) had an intermediate DO of 134 d.

Table 5. Herd structure and proportion of pregnant cows of studied reproductive programs

	Program 1	**Program 2**	**Program 3**
Type of program	HD Only	TAI Only	HD + TAI
Name of program: 1st service	Estrous Detection	Presynch-Ovsynch	Presynch-Ovsynch
Name of program: 2nd service	Estrous Detection	D32 Resynch	D32 Resynch
1st parity cows (%)	41.36	33.56	37.93
2nd parity cows (%)	26.34	24.93	25.82
3rd parity cows (%)	15.65	17.21	16.41
4th parity cows (%)	8.73	11.19	9.82
5th parity cows (%)	4.66	6.98	5.64
6th parity cows (%)	2.20	3.80	2.85
7th parity cows (%)	0.75	1.52	1.05
8th parity cows (%)	0.26	0.61	0.39
9th parity cows (%)	0.09	0.25	0.14
Herd pregnant cows[3] (%)	45.33	52.45	49.01
Days open[4] (d)	146.77	129.82	133.78

[1] TAI = Timed artificial insemination
[2] HD = Estrous detection or breeding after observed estrus
[3] Animals that were 35 or more days in gestation
[4] Average number of days in milk at which cows became pregnant.

DISCUSSION

We are demonstrating with this work the feasibility of simulating a dairy herd on a daily basis to economically compare various reproductive management strategies using detection of estrus, TAI, or a combination of both. Models in the past have used approximations to adjust reproductive programs to the dimensions of the model. Performing a daily simulation has numerous advantages; but principally, it allows study of reproductive programs with detailed precision not reported before.

The timing of the reproductive events in reproductive programs is critical. Previous models have used monthly (Cabrera, 2010; Kalantari, 2010) or weekly (De Vries, 2004, 2006) time intervals and consequently the reproductive programs had to adjust to these time spans. As an example, let's look at the studied reproductive Program 3 that combined TAI with HD and the challenge this would have represented to fit into a monthly step model. This program started with HD at 50 DIM and those cows not observed in estrus would receive first service TAI at 72 DIM and then continued with TAI every 42 d for successive services. After each TAI service HD was performed and cows had the opportunity to receive AI before the following scheduled TAI. In order to match that reproductive program with a monthly step-based model, it would have required compromising the precision of the information by aggregating reproductive performance to pre-determined time spans. For instance, the estimated pregnancies would have been based on a survival curve aggregated every month. Along with the reproductive parameters, the economic parameters would have required merging to pre-determined time spans. As a result, the model would become somewhat insensitive to changes in the IBI as well as to changes in the CR.

The transition matrices and economics in each step of the model are also critical. Another approach that has been used to study reproductive programs has been to adjust the model to reproductive program events (Meadows et al., 2005; Giordano et al., 2010), so the reproductive variables (TAI) are applied as scheduled. However, in event-driven models, there is still a need to aggregate HD and economics to pre-defined periods that are dynamic and dictated by the TAI reproductive program. Also, in event-driven models (as well as in monthly or weekly models) handling abortion and other transition matrices becomes a challenge because of the time when abortion occurs and the next available time in the model where the aborted cow should move. Event-driven models could be somewhat insensitive to small changes on CR, as well as IBI changes. Despite these limitations, simpler event-driven models could still be useful to assess the economic value of reproductive programs for practical purposes when high precision is not critical. An example is a decision support tool, UW-DairyRepro$ (DairyMGT.info/tools.php), recently developed in Wisconsin. Overall, result trends from this simpler model seem to be in agreement with the results reported here.

A daily simulation model overcomes the limitations of previously developed models by allowing very detailed comparison of reproductive programs, including HD and TAI programs and a combination of both. Daily simulation uses, with precision, the transition matrices of abortion, milk production, economics, culling, and death. As seen in the results, economic differences between programs are rather small (Holmann et al., 1984; Lima et al., 2010) and consequently they need to be calculated with extreme care.

The challenge of a daily model lies principally on the organizational dimensioning of the model and on the computational resources required to solve it. Although the problem is solvable, it is still far from becoming a user-friendly decision support system due to the calculation time needed for the model to achieve a steady-state. Nonetheless, the daily model can be used as the *gold standard* to evaluate simpler models aimed for practical decision-making, for example the above mentioned UW-DairyRepro$.

The results from the present study seem to indicate that programs relying more on TAI would have a better reproductive and economic performance. The higher cost of programs including TAI is offset by the economic benefit of an improved reproductive efficiency. Contrary to what was expected, the income over feed cost of the lower performance reproductive program (Program 1, 100 % HD) was the highest of the 3. Having most of the cow population in the first 2 lactations seems to explain this outcome. Nonetheless, the economic benefit of TAI reproductive programs is accentuated by reduced culling and mortality cost and an increased income from additional calving. At the end, although the milk income over feed cost for the 100 % HD program is higher, the programs including TAI have a higher overall value for the reproductive program. The use of HD between TAI prevents a number of cows receiving a TAI, which would have had a higher CR, especially for first TAI. Our results are in agreement with previous reports that have also indicated that pure TAI programs would be more economically beneficial than pure HD programs (Le Blanc, 2001; Tenhagen et al., 2004; Le Blanc, 2007). In summary, having lower DO, more pregnant cows, and reduced proportion of the herd in first parity is economically better.

Making the optimal decision at the time of selecting which reproductive program to use in a 1000-cow herd could translate into as much as $17,050/yr of additional net profit when substituting a pure HD reproductive program for an all TAI reproductive program (Preesynch-Ovsynch and D32 Resynch).

Finally, interpretation of the results should be made within the context of the bio-economic scenarios used for this simulation experiment. The complex interactions among the timing of reproductive events, the shape of the lactation curves, the risk hazard of culling and mortality, and the multiple economic variables might result in different outcomes. Further work is warranted to validate the model outcomes under the multiple conditions observed in modern dairy farms.

CONCLUSIONS

Under the conditions defined for a large commercial Holstein herd, using TAI reproductive programs performed economically better than a pure HD program. The economic value gained by switching reproductive programs varied between $2.60/cow/yr (Presynch-Ovsych, D32 Resynch with HD to Presynch-Ovsych, D32 Resynch without HD) and $17.05/cow/yr (100 % HD to Presynch-Ovsych, D32 Resynch without HD). Economic evaluation of reproductive programs is complex and it is a permanent challenge dairy producers face. Previous models have failed to include the precision needed in the evaluation of reproductive programs. The model described in this paper demonstrates the feasibility of simulating dairy herds on a daily basis to economically evaluate reproductive programs. The challenge of translating the framework reported here to a user-friendly decision support system still remains.

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LITERATURE CITED

Britt, J. H. 1985. Enhanced reproduction and its economic implications. J. Dairy Sci. 68:1585–1592.

Cabrera, V. E., A. De Vries, and P. E. Hildebrand. 2006. Manure nitrogen production in North Florida dairy farms: a comparison of three models. J. Dairy Sci. 89:1830-1841.

Cabrera, V. E. 2010. A large Markovian linear program to optimize replacement policies and dairy herd net income for diets and nitrogen excretion. J. Dairy Sci. 93:394-406.

DeLorenzo, M. A., T. H. Spreen, G. R. Bryan, D. K. Beede, and J. A. M. Van Arendonk. 1992. Optimizing model: Insemination, replacement, seasonal production, and cash flow. J. Dairy Sci. 75:885-896.

De Vries, A. 2004. Economics of delayed replacement when cow performance is seasonal. J. Dairy Sci. 87:2947-2958.

De Vries, A. 2006. Economic value of pregnancy in dairy cattle. J. Dairy Sci. 89:3876-3885.

De Vries, A., J. D. Olson, and P. J. Pinedo. 2010. Reproductive risk factors for culling and productive life in large dairy herds in the eastern United States between 2001 and 2006. J. Dairy Sci. 93:613-623.

Ehrlich, J. 2009. Precision, accuracy, and dimensions of milk production. 17th ADSA Discover Conference on Food and Cow Agriculture: Dairy Herd Analytics, Nashville, IN.

Eicker, S., and I. Fetrow, 2003. New tools for deciding when to replace used dairy cows, Proc. Kentucky Dairy Conference, University of Kentucky, Lexington. pp. 33–46.

Fricke, P., S. Stewart, P. Rapnicki, S. Eicker, and M. Overton. 2008. Pregnant vs. open: Getting cows pregnant and the money it makes. eXtension, Dairy, Available at: http://www.extension.org/pages/Strategies_for_Optimizing_Reproductive_Management_of_Dairy_Heifers.

Giordano, J. O., P. M. Fricke, M. C. Wiltbank, and V. E. Cabrera. 2010. A stochastic evaluation of reproductive management programs for dairy herds. J. Dairy Sci. 93(E-Suppl. 1):807.

Groenendaal, H., D. T. Galligan, and H. A. Mulder. 2004. An economic spreadsheet model to determine optimal breeding and replacement decisions for dairy cattle. J. Dairy Sci. 87:2146–2157.

Holmann, F. J., C. R. Shumway, R. W. Blake, R. B. Shwart, and M. Sudweeks. 1984. Economic value of days open for Holstein cows of alternative milk yields with varying calving intervals. J. Dairy Sci. 67:636-643.

Jalvingh, A. W. 1993. Dynamic livestock modeling for on-farm decision support. Ph.D. Diss., Wageningen Agricultural Univ., Wageningen, The Netherlands.

Kalantari, A. S., H. Mehrabani-Yeganeh, M. Moradi, A. H. Sanders, and A. De Vries. 2010. Determining the optimum replacement policy for Holstein dairy herds in Iran. J. Dairy Sci. 93:2262-2270.

LeBlanc, S. 2001. The OvSynch breeding program for dairy cows: A review and economic perspective. Bov. Pract. 35:13–22.

LeBlanc, S. 2007. Economics of improving reproductive performance in dairy herds. Western Canadian Dairy Seminar: Adv. Dairy Tech., 19:201-214.

Lima, F. S., A. De Vries, C. A. Risco, J. E. P. Santos, and W. W. Thatcher. 2010. Economic comparison of natural service and timed artificial insemination breeding programs in dairy cattle. J. Dairy Sci. 93:4404-4413.

Meadows, C., P. J. Rajala-Schultz, and G. S. Frazer. 2005. A spreadsheet-based model demonstrating the nonuniform economic effects of varying reproductive performance in Ohio dairy herds. J. Dairy Sci. 88:1244–1254.

Olynk, N. J., and C. A. Wolf. 2009. Stochastic economic analysis of dairy cattle artificial insemination reproductive management programs. J. Dairy Sci. 92:1290-1299.

Silva del Rio, N., S. Stewart, P. Rapnicki, Y. M. Chang, and P. M. Fricke. 2007. An observational analysis of twin birds, calf sex ratio, and calf mortality in Holstein dairy cattle. J. Dairy Sci. 90:1255-1264.

St-Pierre, N. R., and L. R. Jones. 2001. Forecasting herd structure and milk production for production risk management. J. Dairy Sci. 90:1255-1264.

Tenhagen, B. A., M. Drillich, R. Surholt, and W. Heuwieser. 2004. Comparison of timed AI after synchronized ovulation to AI at estrus: Reproductive and economic considerations. J. Dairy Sci. 87:85–94.

Van de Haar, M, H. Bucholtz, R. Beverly, R. Emery, M. Allen, C. Sniffen, R. Black. 1992. Spartan dairy ration evaluator/balancer. An agricultural integrated management software microcomputer program. CP-012 Version 2.01. CES, AES. Michigan State University. East Lansing.