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Microcomputer Simulation of Management Practices Affecting Timing of Net Income in Dairy Cattle

by

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(ABSTRACT)

Microcomputer simulation was used to evaluate effects of all combinations of two levels of involuntary culling, heifer rearing, and sire selection against dystocia in heifers on timing and magnitude of net income in dairy cattle. Time to cumulative payoff of expenses and net income per day of herdlife were measured for herds and individual cows. Net income was accumulated monthly, and expressed per day of life and per day to 96 mo. Twenty herds of 80 cows were simulated for 20 yr under eight options in the herd study. More than 1000 cows with complete herdlives, from a single herd, were individually simulated for each of eight options in the cow study, with no voluntary culling of cows.

For the herd study, milk yield per cow averaged 6838 kg ± 858 kg/yr, and net income per cow was $671 ± $193/yr. Mean time to payoff was 60.0 mo, and mean net income to 96 mo, including salvage value, was $.36/d. Heifers calving at 26 mo had rearing expenses of $1030, time to payoff of 54.6 mo, and net income of $.432/d, compared with rearing expenses of $1200, time to payoff of 70.0 mo, and net income of $.285/d for heifers calving at 32 mo. Options with 12% involuntary culling paid off 2.3 mo earlier and had $.081 more net income per day than 24% involuntary culling. Differences in response variables due to sire dystocia and PD Dollars were minimal. Options with 26 mo age at first calving, 12% involuntary culling, and random mating

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had earliest time to payoff (54.0 mo) and highest net income (\$.485/d). Options with 32 mo age at first calving, 24% involuntary culling, and random mating had latest payoff (74.3 mo) and lowest net income (\$.246/d). Herds and years had large effects on time to payoff and net income due to differences in herd production and genetic trend of sires for production over time. Including salvage value for cows surviving 96 mo increased net income \$.064/d for herds, and \$.25/d for cows. Twenty-one percent of the value of increased milk yield was attributed to increased feed costs.

For the cow study, cost of rearing heifers was \$1141 ± \$127, mean time to payoff was 53.4 mo, and mean time to cumulative profit was of 56.5 mo. Cumulative profit represented positive cumulative net income for 12 consecutive mo, which included 69% of cows with time to payoff. Net income was \$.19/d for all cows, \$.46/d for cows with a first calving, \$.60/d for cows surviving 96 mo, and \$.85/d for cows surviving 96 mo including salvage value. Heifers calving at 26 mo paid off expenses at 47.1 mo, compared with 60.6 mo for heifers calving at 32 mo. Heifers calving at 26 mo cost \$.07/d more to raise to first calving, but paid off by 70 d in milk into their second lactation, compared with payoff by 140 d in milk of the third lactation for cows calving at 32 mo. Regressions of time to payoff and net income per day at 96 mo on cow production were -.0077 d/kg and .00028 \$/kg, respectively. The regression of time to payoff on PD Dollars was -.0035 d/PD\$, and the regression of net income per day on PD Dollars was .00072 \$/PD\$ for cows that calved. Differences did not exist in time to payoff between levels of involuntary culling and selection against dystocia.

Heifer rearing was most important in this study due to large differences in time to payoff and net income as age at first calving changed. Sire selection against dystocia in heifers was least important due to the mating program used, with intermediate differences in payoff and net income between levels of involuntary culling.

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Introduction

Management is frequently described as the process of making decisions. Management of a dairy farm requires decisions to be made that affect operations and influence profit in both the short and long term. Effective decisions require judicious allocation of resources so that established goals are achieved. Individual goals vary greatly, and include goals for the farm business, herd productivity, and personal ambitions. Setting realistic goals, and using available financial resources to effectively accomplish these goals, ultimately determines the success of the farm.

Acquisition of adequate financial resources to implement decisions is important in achieving goals. Well managed farms generally have more money available for resource allocation, because decisions over time have enhanced profit. If a farm manager wishes to improve profit, factors that have a major impact on receipts or expenses must be identified and addressed.

To evaluate whether management changes affect profit, three requirements need to be fulfilled. First, the magnitude of change in profit as a result of change in management must be recorded at specified intervals. Second, differences in income and expense should be evaluated for many cows in several herds to determine if differential response due to herd management is evident. Finally, data should be collected over a long period of time, usually several years, to determine the long term effects of changing management. The effect of a management change can be manifested in differences in income or expense, as well as the timing of income or expense.

Collection of financial and production data on a monthly basis from actual herds is expensive, time consuming, and not always complete or accurate. Hypotheses to be tested under research conditions often require operations contrary to the goals already in place on commercial farms, and in conflict with other projects at research farms. One possibility for the relatively inexpensive collection of large amounts of complete data is through computerized simulation of the dairy enterprise. Because simulation can be used to "compress" time, i.e., years of real-life time can be reduced to minutes of simulated computer time, simulation can effectively allow evaluation of the consequences of adopting new technologies and strategies. Simulation could be an asset to a research program if relationships and parameters of biological variability are known because of the advantages of computer speed and reduced expense. Expenses are reduced because it is not necessary to invest in an inventory of cows and supplies, and hire labor to manage procedures and collection of data.

For a tool such as simulation to be effective for instructional and research purposes it must be able to create situations that represent dairy farms. With respect to animals, growth, milk production, and susceptibility to common diseases must be considered. Simulated milk production should reflect daily variability of yield within cows caused by environmental change, variability among cows within the same herd due to genetic ability and individual differences, and variability among herds due to differential management and other conditions. It is imperative for realism to include relationships between production and the effects of reproductive status, health status, and nutritional status of individual cows.

Computerized simulations in dairy science have several limitations. The major limitation has been computing facilities. The earliest simulations were written in structured computer languages designed for use on mainframe computers. More recently, simulation "packages" have been developed which allow easier programming of simulations, but hamper distribution to other interested parties because of copyright laws. Most of these programs are still designed to operate on mainframe computers. During the last few years, attempts have been made to produce simulations on mini- or microcomputers rather than mainframes. Problems have been encountered concerning computing time as microcomputers operate significantly slower than mainframes. Minicomputers have not provided much compatibility among researchers. Other problems concern the cost of development and incompleteness of the simulation programs.

Many simulations related to dairy science have been developed by reproductive specialists and veterinarians to evaluate reproductive problems and culling policies. While important, they ignore individual cows with regard to genetic selection and management decisions not involving reproduction directly, and important relationships between production and reproduction within a lactation and across lactations within cows. The first objective of this research is to develop a dairy herd simulation program that will:

- Run with moderate speed and ease on a microcomputer.
- Allow a finite number of management decisions to be made on a simulated yearly or more frequent basis.
- Establish a genetic basis, including matings between cows and bulls, as the central component of the simulation.
- Contain relationships between production, nutrition, and reproduction within and between lactations on individual cows.
- Include a model segment to simulate heifer rearing practices.
- Record output for statistical analyses of alternative management options.

The second objective of this research is to use the simulation in a designed experiment to examine the relationship of several management alternatives with net income of the dairy cow. The time required for a cow to offset her rearing expenses plus the cost of production after first calving, and the magnitude of income and expenses over this time, are of primary importance. In this study net income is expressed on a cash basis as income received from milk, fat, cull cows, bull calves, and pregnant heifers, minus fixed expenses, feed expenses, breeding expenses, and health expenses. Fixed expenses include housing, labor, taxes, and insurance, but do not include interest on average investment. Levels of sire selection against dystocia, heifer rearing expenses, and involuntary culling of cows and heifers will be evaluated with respect to net income. Continuous effects of individual production and sire selection for PD Dollars will be considered. Importance of these factors will be determined by the magnitude of their effects on net income and the number of months to cumulative payoff, including interactions among the effects. Cows will be analyzed separately from herds because many model assumptions are sensitive to culling policies. Simulation of herds will utilize voluntary culling that approximates actual farm policies. Simulation for the cow analyses will not include voluntary culling, thus allowing all cows the opportunity to earn income over a potential lifetime.

Properly programmed, this simulation will allow the researcher to evaluate the effects of advanced technology or improved management decisions on individual cows and entire herds. Examples of factors to evaluate could be the incorporation of new feed additives into a ration, administration of bovine somatotropin to cattle, and economic evaluation of differences in conception rates of sires. For students, this simulation could be a training tool that is challenging to operate and educational in the sense that the consequences of management decisions can be observed and compared without financial risk.

Review of Literature

The use of simulation to study problems involving dairy cattle is not new to the dairy industry. Publications appear in the literature that date back many years documenting simulation programs. Two improvements have facilitated the analytical approach to current day problems using simulation. First is the advent of high speed, large memory mainframe computers during the past 25 years. Second are improvements in parameter estimation of, and relationships among biological systems of the cow. The major objective of this literature review is to survey important simulation work published since 1977. Emphasis will be placed on development and operation of these simulations, rather than particular equations used to predict biological values for cows.

Evaluation of simulation programs developed since 1977 reviews progress from structured language programming through packaged simulations on mainframe computers, to simulations on mini- and microcomputers during more recent years. This review is presented in chronological order and by author to provide a simple overview of their development. Other important work, such as parameter estimation of characteristics for biological systems, will be introduced in the materials and methods as they are incorporated into a new simulation model. Most simulation work reviewed in this study is directly related to modelling of dairy cattle systems. Simulation in other areas, particularly beef cattle systems, has also been done (50, 59). However, many of the assumptions related to beef cattle, i.e. crossbreeding and management options, do not directly apply to dairy cattle management.

Dairy cattle simulations developed in the 1960s were used primarily for instructional purposes. A single trait dairy cattle breeding simulation was developed by L. D. McGilliard at Michigan State University as an aid for teaching principles of breeding and genetics. It did not allow for exchange of animals between herds and did not use AI sires for matings. R. L. Willham and G. Thompson at Iowa State University developed a multiple trait beef simulation that had fixed herd size and allowed for the use of AI sires in matings. At Ohio State University, W. R. Harvey developed a simulation for swine breeding that contained litter effects, and L. D. VanVleck at Cornell University also developed a breeding simulation for dairy cattle (McGilliard, M. L., 1988. Personal communication). The major objective of these simulations was as a classroom aid for teaching topics related to selection and genetic inheritance. These simulation programs were not generally used as research tools.

Simulation by Stewart

The objective of the Stewart et al. (78) simulation in 1977 was to estimate the effect of differing economic conditions on culling decisions utilizing a dynamic programming model. This research expanded to Holsteins their previous work evaluating culling decisions in Jerseys. Economic conditions were represented by changes in milk, beef, and feed prices, plus replacement costs, interest rate, and length of planning horizon. Culling decisions were based on age, milk yield, milk fat percentage, body weight, and expected profit of individual cows. Later work of Stewart et al. (77) was expanded to other breeds.

A dynamic programming model was used to create records representing dairy cows. Dynamic programming is a mathematical procedure used to divide a multidimensional problem into a smaller number of independently solvable single-dimension problems. They stated the dynamic programming approach was superior to linear programming techniques as it allowed for adaptation of probability statements to specific events, such as probability of survival to successive lactations. Linear programming does not have the capability of incorporating probability statements. Dynamic programming seems to be a combination of linear programming and simulation.

Discrete values were created for lactation number, 305-day milk yield, fat percent, and body weight. Lactations were numbered from 1 to 7. Eleven levels of milk yield were created at 500 kg intervals from 4000 kg to 9000 kg. Seven fat percent levels were created at .2% intervals from 3.1% to 4.3%, and five body weights were created in 100 kg intervals from 450 kg to 850 kg. The dynamic programming model required that these values be discrete. The factorial combination of these factors represents 2695 possible outcomes.

It does not appear as if records representing cows were simulated using random numbers to create characteristics of cows, as there was a record present for each of the 2695 combinations of factors. It appeared that 2695 initial records were created representing all combinations of milk yield, fat percent, lactation number, and body weight. No other parameters or relationships between parameters were used in their model. These cows were then moved through simulated years of time, incrementing lactation number, and adjusting milk yield and fat percent reflecting the age of the individual. Simulation utilizing random numbers was used to determine the probabilities of survival to successive lactations, death, involuntary and voluntary culling, and subsequent replacement. Body weight change for cows over time was small, so a cow's initial estimated body weight was not changed during her lifetime.

The simulation created records representing individual cows, however the cows were not grouped into herds. Therefore, herd differences were not considered in this simulation. Culling decisions were based on projections of income over a 10 yr planning horizon. Individual cows could be removed from the simulation through death or involuntary culling for reasons other than death. Voluntary culling decisions were based on low production, type faults, sale for dairy purposes, or problems that did not require involuntary culling. An example of involuntary culling is failure to conceive. Probabilities of culling were assigned to each of these voluntary reasons and were included in the model.

For each cow not culled through probability distributions, the decision to cull was made individually in the simulation at 60 d post calving, based on whether the cow or her replacement would return more profit. Two values for profit were calculated from milk returns, beef sales, feed costs, replacement costs, and cow depreciation over the 10 yr planning horizon. First was a keep value, which was the expected profit for the cow over her remaining life if she remained in the herd. This figure included milk sales, probability of survival to future lactations, replacement costs, plus returns credited to her replacement should the cow be removed. Second was a replace value, calculated as the expected profit assuming the cow was culled immediately and replaced with a first lactation heifer. The replace value included salvage value for the cow, plus future returns from the replacement. Future returns from a replacement were subject to the same probabilities of death, replacement, involuntary and voluntary culling as other cows with similar biological characteristics. All replacement heifers had identical characteristics, meaning they were all first lactation heifers, weighing 550 kg, with yield of 5000 kg of 3.5% milk. The one exception to this was that in consecutive years the replacement heifer's value for milk yield increased by 45 kg/yr to account for genetic progress in the population. The culling decision for each cow was to keep or replace. The cow was kept if her keep value was larger, and replaced if her replace value was larger.

Different economic conditions were created using a high, average, and low value for each income or expense item. The prices received for milk were estimated from 1974 Canadian economic records from Ontario, and were $15.40, $22.00, and $28.60 per 100 kg milk. Prices received for beef sales were $33, $44, and $55 per 100 kg body weight for salvage value. Feed intake of corn silage, hay, haylage, and concentrate was determined by size and milk yield of the cows. Costs for each ingredient varied in a manner similar to beef and milk prices. Cow depreciation was included in the profit equation, and was estimated as the value of the cow in the previous year minus the cow's current value. Interest rates were 7, 11, and 15%.

The base model for economic analyses included all prices and costs at their medium value, at which time a keep versus cull decision was made for each cow. Thirteen additional models consisting of combinations of high, medium, and low price for milk, beef, and feed, plus the three interest rates were evaluated over the 10 yr horizon. These models included high and low milk price, holding other prices and costs at their medium value. Similarly, high versus low beef price, feed cost, and interest rate were evaluated. Other models contained high and low values of all prices and costs at the medium interest rate. It was determined that culling decisions changed under these different economic conditions if a cow was kept under one set of conditions, but culled under another.

Stewart found that in approximately 95% of the cases the decision to cull or keep a cow was not dependent on the milk, beef, or feed price, or the interest rate used. For the remaining 5% of the cows, increasing milk price from medium to high was associated with more intensive culling of lighter cows and less intensive culling of heavier cows. The increased income from milk could offset the higher maintenance cost associated with larger cows in this case. When milk price was low, fewer of the lighter cows were replaced. The fact that all replacements weighed 550 kg, and would likely have higher feed costs than lighter cows would seem to be a major contributor to this.

Changes in culling due to variation of beef prices were minimal. Less than 1% of the decisions to cull or keep a cow changed when beef price changed from $45 to $55 per 100 kg. This was partially due to purchasing replacements based on their weight, which would offset gains in salvage value of the cows with increases in the purchase price of replacements. Similarly, for lower beef prices cows returned less for salvage value but the replacements cost less, with the decision to cull essentially unchanged.

Increasing feed cost was associated with less culling of light cows and more culling of heavier cows. This was because all cows were replaced with a 550 kg heifer, thus giving an advantage to replacement of heavier cows that required more feed for maintenance. When milk price, beef price, and feed cost were all high, heavier cows were culled more intensively. Lighter cows were culled more intensively when all prices and costs were low. When interest rate increased from 11 to 15%, cows in all categories of factors were less intensively culled. Because of the discounting factor used, as interest rate increased more importance was placed on the cow's current production and value. Therefore, cows in later lactations that produced more current milk would have an advantage over heifers that would produce more milk in future years. For the low interest rate where future lactations of replacement heifers would receive more emphasis, there was more culling of older cows. Also, with low interest rates cows would depreciate at a slower rate, thus increasing the current value of younger cows.

The source code and programming language used to develop the Stewart simulation were not available. Probability distributions used to determine reasons for disposal were not published. Thus, it was difficult to evaluate performance of the model. Emphasis will be placed on how the variables were created with desirable and undesirable qualities of the model noted with respect to simulations in general.

Initially, body weight was estimated once per lactation immediately following calving. This would not allow evaluations of body weight change within a lactation. Also, large differences existed between body weight categories for cows, and predicted yearly changes in body weight for individual cows were small. Consequently, an animal's initial weight assigned in the simulation did not change appreciably during her lifetime. Another problem with the assignment of body weight was that all replacements were assumed to weigh 550 kg. All levels of milk yield were established at the beginning of the simulation. Milk yield for future lactations was estimated using transition factors prior to each yearly run of the model. This allowed for incorporation of current lactation production in culling decisions. Complete lactation yield was simulated rather than using a lactation curve and accumulating yield over time. Multiplicative and transition factors were used to modify milk yield and fat percent across lactations for all cows, but there was no evidence that lactation yield was modified differently from one individual to another.

There seems to be no consideration of genetic value for milk yield along with permanent and temporary environmental effects for yield. Selection of sires for breeding and actual matings were not considered in this model. Genetic progress was assumed to be 45 kg per year for each group of heifers with no individual consideration given to animals. Although these factors might have a minimal effect on the outcome of the model with respect to culling decisions, it does not appear that this model would be representative of real life continuity utilized in other simulations.

Culling decisions, or voluntary removals were made only at one point in time during the lactation, at 60 days post calving. This allowed for equal comparisons among all animals, but this style of culling is not normally practiced on dairy farms and culling decisions are not normally identical in timing. Culling is usually applied to cows that do not conceive, fall below a specified production level, or have functional type or health problems, and could occur at almost any time during the lactation. When an animal was culled in this simulation, she was replaced by a heifer that weighed 550 kg and produced 5000 kg of 3.5% milk. It would seem desirable to determine individual characteristics for replacements from probability distributions. This could be done by simulating a replacement program, as done by Toro (85). Later work by Stewart et al. (77)

incorporated variability in production of first lactation heifers through use of a probability distribution.

Cows could be voluntarily or involuntarily removed by the Stewart simulation. The basis for voluntary and involuntary culling was sound. However, reasons for culls were not distinguished. For example, a cow that was involuntarily removed was not distinguished as injured, diseased, or mastitic, but rather just an involuntary cull. The four categories of culling were died, sold for dairy, involuntary cull, and voluntary cull. When animals were voluntarily culled at 60 d post calving, it was assumed that feed costs during the dry period and the first 60 d of lactation offset milk income for the lactation up to that point.

Other model characteristics that simplified real herd situations were that all cows in a herd were fed in the same manner, and a constant calving interval of 12 mo was used. Reproductive performance, milk yield, and body weight were assumed independent. Since these were essential to culling decisions and overall animal performance, it seems as if the omission of these correlations could be of critical importance to a model, depending on the objectives of that model. The Stewart model was one of the earlier simulations developed, and has been used as a basis for development of more advanced models by other authors. However, lack of relationships between milk yield and reproductive performance, combined with the discrete nature of many of the variables would limit the effectiveness of this model. Estimates of relationships between production and reproduction have been developed by other authors (34, 44, 45, 46) since the Stewart model was published, and could improve performance of this model.

Simulation by Oltenacu

Oltenacu et al. (62) developed in 1980 a simulation to model reproductive performance in a dairy herd. The program was designed for mainframe computer use with the General Activity Simulation Program (GASP). GASP is a simulation "package", which means the code for the simulation is already developed and the operator uses the simulation through input of parameters. Their primary interest was how various reproductive policies affected indicators of reproductive performance. The early work was directed at reproductive performance only, and did not include information on milk production or feed intake. These variables were added to the model in a subsequent analysis (63) and will be discussed later.

The Oltenacu et al. (62) model was based on next event simulation. The four events simulated were parturition, ovulation, embryonic loss, and replacement. Policy or control variables were those controlled by the operator of the program. They were first breeding policy, reproductive culling policy, heat detection program, breeding program, and sire selection program. Other important variables were parturition type (normal vs abnormal calving), estrus behavior, cow fertility, embryonic mortality, and the non-reproductive culling rate. Response of the reproductive program to different levels of these variables was measured by days to first service, days from first service to conception, days open, number of services per conception, and calving interval.

The mathematical model and probability distributions used to create individual characteristics were well described. Oltenacu made extensive use of probability distributions to describe the variables. The model simulates biological characteristics of individual animals, and effects in the model were incremented on a daily basis. In addition to being set by the operator, control variables had alternatives that could be applied to individual cows, groups of cows, or the whole herd. For example, under the first breeding policy, the operator could set the policy for days to first service as a specified number of days, the first heat observed on a cow, or the first heat after a specified number of days from freshening. Cows with a history of reproductive problems could be treated differently from normal cows.

The many relationships in the model will be discussed individually in the context of a cow progressing through her reproductive cycle. The beginning of the reproductive cycle, parturition, was classified as either normal or abnormal. Abnormal parturition included occurrences such as dystocia, twinning, or retained placenta. The probability that a parturition was abnormal followed a Bernoulli distribution with the equation described in Table 1. The Bernoulli distribution represents the probability of occurrence of a discrete variable that has only two outcomes, and was used for the description of events such as normal versus abnormal calving. Uniform random numbers were used to estimate the Bernoulli occurrences. The probability of an abnormal parturition was dependent on age of the individual only, described as the cow's lactation number. The probability of a normal parturition was (1 - probability of an abnormal parturition).

Abnormal calvings had a negative effect on time to first estrus and the cow's fertility when she came into estrus. The distribution and parameters used to create the time to first estrus are in Table 2 for normal and abnormal calvings. Animals having abnormal calvings took longer to reach first estrus. Both distributions, as many of the others used by Oltenacu, were truncated to eliminate unreasonable numbers at extreme ends of the distributions. Abnormal calvings also affected fertility of the female. Assuming that a normal calving resulted in normal fertility as per the equation in Table 1, abnormal calvings had the following effect on fertility. Ten percent of these cows would become sterile and the remainder would have 80% of normal fertility at their first estrus. For each estrus following, one half of the abnormal cows would return to normal fertility for up to six estrous cycles. Two situations were considered for a cow that came into estrus.

Table 1. Equations used by Oltenacu et al. (62) to predict probabilities of occurrence for reproductive variables.

Variable	Equation[1]	Distribution
Parturition abnormal	$.36 - (L - 1) \times (.15)^L$	Bernoulli
Cow fertility[2]	$.42 + .24 \times (CY) - .028 \times (CY)^2 - .003 \times (L) - .0036 \times (L)^2$	---
Embryo loss	$.08 + .01 \times (L)$	Bernoulli
Non-reproductive culling[3]	$.091 - .007 \times (L) + .006 \times (L)^2$	Bernoulli
Cow shows estrus	.4 if $CY = 1$, .8 if $CY = 2$, .95 if $CY = 3$, 1.0 if $CY \geq 4$	Bernoulli

[1] L = lactation number (L = 1,2,...10). CY = estrous cycle (CY = 1,2,...6).

[2] This equation estimates fertility as conception rate. Fertility for an abnormal calving is 80% of this value.

[3] For (L = 1,2,...9). Probability of being a non-reproductive cull is 1.0 for L = 10.

First was the possibility the cow would physically show heat. Second, herd management options for heat detection determined the proportion of observable heats that were detected. The probability that a cow showed heat was dependent on the number of estrous cycles she had and followed the Bernoulli distribution described in Table 1.

The heat detection program was classified as good, average, or poor. These policies were associated with the following herd management options, and response was measured by differences in the rate of heat detection. Good heat detection policies were represented by three 30 min observation periods when the cows were not in the milking process, with a resulting heat detection rate of 75%. Average heat detection was represented as checking for heat before each milking, with a heat detection rate of 55%. Finally, a poor heat detection program consisted of checking for heat at random times during chores, with a heat detection rate of 35%. Probability of observed heat was the product of the probability a heat occurred and the rate of heat detection.

Once a heat had been detected, the decision to breed an animal was determined by two factors. The first breeding policy determined whether the animal would be serviced or not based on the policy chosen by the operator and the number of days post partum of the cow. Additionally, the reproductive culling policy had an effect on whether an animal was serviced, as it determined if a cow would be culled after a given number of services, specified number of days open, or for other reproductive problems.

If a cow was serviced, conception was determined from a Bernoulli distribution, and was defined as the probability of a particular service resulting in conception. That probability was determined by the fertility of the cow and bull, and the effectiveness of the inseminator. Cow fertility was discussed previously. Although sire fertility could be set at any level by the operator, it was assumed to be 75% for all sires in this simulation. Effectiveness of the inseminator was a combination of skill of the inseminator and timing of the insemination, with the value of inseminator effectiveness ranging from

Table 2. Distributions and parameters used by Oltenacu et al. (62) to create time related reproductive variables.

Variable[1]	μ	σ	Conditions[2]	Distribution
Parturition to first estrus				
Normal calving	30	25	$10 \leq d \leq 80$	Gamma
Abnormal calving	50	35	$20 \leq d \leq 100$	Gamma
Time between estrous cycles after first	21	4	$12 \leq d \leq 30$	Normal
Time to embryo loss[3]	25	10	$25 \leq d \leq 75$	Normal
Time of gestation	278	6	$266 \leq d \leq 290$	Normal

[1] All variables measured in days.

[2] Distributions are truncated to eliminate unreasonable values (d = number of days).

[3] Values are from a Normal distribution with mean 25 d, but truncated so that values cannot be less than 25 d.

zero to one. Measures of effectiveness were input by the operator as discrete values similar to the rate of heat detection. Conception rate was the product of the cow's and bull's fertility, times the effectiveness of the inseminator. Under ideal conditions, maximum expected conception was 58%.

If conception did not occur, the cow was passed through the simulation to the next estrous cycle, where the decision to breed was made again. Conditions such as number of days open and number of services were incremented accordingly and used in the next decision to breed. If conception did occur, the probability of embryonic loss was considered next. Embryonic loss followed a Bernoulli distribution which was dependent on age of the cow only (Table 1). If there was embryonic loss, the cow returned to normal reproductive cycling and fertility. If there was no embryonic loss, the cow was assigned a gestation period from a Normal distribution described by parameters in Table 2. Non-reproductive culling was determined at this point according to the parameters in Table 1, dependent on age of the cow. All cows were culled after 10 lactations. The probability of abortion was not considered in this model. If non-reproductive culling did not occur, the gestation was completed, a parturition would occur, and the cycle would start again.

Many of the estimates used for the Oltenacu simulation were from the literature. However, lack of several relationships could limit implications from the model and model performance. Most important was this simulation included no relationships between reproductive performance and milk yield, as milk yield was not simulated. This precludes economic analyses of the effect of reproductive policies on income because there was no source of income in the model. Inclusion of milk yield for cows, with appropriate relationships included with reproductive parameters, would provide economic information to evaluate the importance of changing reproductive policies. Another weakness of the model for broader situations was that sire selection was limited to fertility of the bull and calving ease of the progeny. Calving ease was not considered in this study. There were no genetic or environmental components of fertility specified, nor was there any consideration of sire merit for production traits. Although it appeared individual matings could be made in this simulation, all matings were to a bull of 75% fertility. This was equivalent to a program with no sire selection or all selections "average."

Effects concerning the heat detection program and skill of the inseminator were limited because of their discrete nature and the small number of categories (n = 3) for each variable. Improvement might be possible if the user were queried for several inputs concerning these variables, with the simulation program assigning the rate of heat detection from a continuous distribution. A possible range of values could be from 35% to 75%. This would be an advantage over the three discrete levels suggested by Oltenacu if one were attempting to create realistic biological variation in heat detection. Values estimating merit of the breeding program could be assigned in a similar manner.

This model was validated by checking its performance against field data with respect to means and variability of reproductive measures. For validation, most simulation variables were held constant at their average while the parameters of heat detection and breeding program were allowed to change. The model was determined to accurately predict reproductive performance as compared to these field data.

Later work published in 1981 expanded the original model to include feed consumption, milk yield, and the relationship between milk yield and reproductive performance (63). Their interest was to determine economic differences associated with varying heat detection programs and conception rates as influenced by the breeding program. The model used to predict daily milk yield included effects of days in milk, days open, days pregnant, age and season of freshening, and the cow's producing ability. It did not appear that genetic merit of the cow or sire was directly included in the prediction of milk yield. Genetic merit for yield was included in the cow's own producing ability which would also include environmental effects for production. Also, it did not appear that various management decisions could affect milk yield. Individual sire selection and mating were not used in this simulation. Additionally, other meaures of production, such as fat yield, fat percent, and protein yield were not calculated. Oltenacu calculated total days in milk for three lactation groups as a function of days open, which seems a desirable method for the decision of when to end a lactation. This allows lactations to be shorter or longer than 305 d depending on the cow's reproductive status.

Oltenacu et al. (63) estimated the effect of milk yield on reproductive performance by regression of conception rate at first service on average daily milk yield during the first 60 d of the lactation. The estimate used a 10% difference in conception rate between cows one standard deviation above and one standard deviation below the average daily milk yield. Males were assumed to have 65% fertility, which was lower than the 75% used in their first analysis. There was no effect included in the model associating yield with days to first service or other reproductive variables. Feed costs were determined from least cost total mixed ration formulations for three production groups of cows, plus dry cows. Nutritional requirements for growth of cows during the first and second lactations were accounted for by increasing daily milk yield 4 kg and 2 kg, respectively in equations for nutrient requirements. This would cause feed intake to be higher in these cows. Feed costs were calculated from feed prices, storage and feeding losses, and cost per kg of dry matter consumed. Apparently, dry matter consumption was estimated from milk yield only. No mention was made of body weight or fat percent estimation, which would effect dry matter consumption.

Additional costs included in the model accounted for breeding and heat detection costs. Heat detection costs were directly related to the time spent observing cows for heat. Breeding costs for poor, average, and good breeding programs were $6, $10, and $18 per breeding. Quality of the breeding program was measured by conception rate. Poor breeding programs cost $6 per service period, consisting of one unit of semen and direct service using an inexperienced inseminator. This resulted in a conception rate of 42%. Average breeding programs cost $10, and consisted of one unit of semen serviced by an experienced AI technician, for a conception rate of 50%. Good breeding programs cost $18, used two units of semen serviced by an experienced AI technician, and yielded a conception rate of 58%. Only one of these breeding programs could be used in a herd at a given time, implying cows could not be handled individually. If cows could be treated individually, it might be appropriate to include these costs on an individual cow basis.

As heat detection programs improved from 35% to 55%, Oltenacu determined there were decreases of 17 d open, 19 d to first breeding, and 7.8% cows culled for reproductive purposes, with an increase of .2 services per cow. The largest economic advantage (+$60 per cow per year) was realized by changing from poor to average heat detection. The increase from average to good heat detection resulted in +$4 per cow per year. These were calculated holding other variables constant at average.

Increasing conception rate from 42% to 50% when heat detection rate and days to first breeding were held average did not change days to first service, and days open were reduced 4 d. However, decreases of .2 services per cow and 3.2% cows culled for reproductive purposes as conception rate increased were relatively more important. The economic advantage gained from changing from poor to average conception rate was +$39 per cow per year, and changing from average to good conception rate reduced income by $7 per cow per year. This was probably due to the high cost per service ($18) associated with high conception, as it required two units of semen and an experienced AI technician. Fixed and variable costs not directly related to reproductive variables were not included in these analyses. There was no mention of a replacement program other than to list the average price ($950) for a replacement animal.

Simulation by Congleton

Congleton (14), in 1984, developed a simulation using the GASP IV simulation package to investigate general dairy management strategies. Application of this program dealt with the relationship of herdlife to annual income of individual cows. However, it seems the major emphasis of this work was validation of the model through comparison to survey information. Included in the model were economic and production information, as well as simulation of discrete (calving, breeding, culling) and continuous (milk yield, feed consumption) variables.

Estimates of many biological relationships were obtained from the literature. The model generally covered more areas of importance related to dairy herd management than previous models (62, 63, 77, 78), but in some cases covered relationships in less detail than previously reported. For example, the reproductive segment of the model in Congleton's simulation was similar to, but less detailed than the reproductive program simulated by Oltenacu.

Congleton developed his simulation in modular form. There were six subroutines used for simulation of breeding, drying off, freshening, milk yield, culling, and replacement. Discussion of the simulation will revolve around each subroutine. Interrelationships between model components were included in these subroutines, but relationships across subroutines generally had no feedback mechanism. Congleton attempted to identify causal relationships between variables in model development, i.e., that increasing milk yield resulted in increased health costs. This would seem appropriate for certain types of relationships. The purpose was to create some factors that would determine output of others. Output from the model was verified for validity by comparison to two Northeast dairy farm survey summaries for performance and economic information.

The simulation will be presented by example of a cow moving through one cycle of reproduction and lactation, assuming that freshening would start that cycle. Records representing individual animals were kept in two files, one for cows in the milking herd and the other for replacements. Continuous processes such as milk yield were calculated and incremented daily, but because of the event simulation of GASP IV these updates were performed in blocks of time. For instance, after freshening the cow was passed to a subroutine to calculate characteristics related to breeding (i.e., days open and date of conception), and milk yield up to that point in time was calculated and accumulated.

When a cow freshened a subroutine was called to determine characteristics of the current lactation. Incidence and costs attributed to mastitis were determined as a function of mastitis incidence in the previous lactation and age of the cow. Only clinical mastitis cases were simulated, and a charge was incurred for discarded milk and treatment costs. These charges increased for older cows, but within a lactation all cows were charged equally. No consideration was given to effects of subclinical mastitis on milk yield or to the fact that treatment and lost milk costs could vary depending on the severity of the mastitis case and daily milk yield of the cow. Both could be affected by stage of lactation of the cow when she contracted mastitis. Addition of somatic cell count information to the model, combined with the relationship of somatic cell count with milk yield and mastitis incidence, would allow calculation of clinical mastitis, subclinical mastitis, and milk loss due to mastitis as a result of the cow's somatic cell count. Additionally, fitting a distribution varying mastitis incidence over time might aid in assigning milk loss and cost of treatment to individual cows. Mastitis incidence over time was simulated by quarter of the udder infected in a subsequent update to this model (19).

Incidences of reproductive diseases or conditions that occurred during the lactation were calculated at freshening. Many conditions were simulated including dystocia, retained placenta, metritis, cystic follicles, luteal cysts, and twinning. Interactions between specific conditions, such as retained placenta and metritis, were included in the model. Effects of reproductive diseases were manifested in decreased milk yield (increased yield with cystic follicles) and costs of treatment for each disease. Most diseases and conditions were dependent on age of the cow or occurrence of another disease in the same lactation. Diseases and conditions were discrete, either the cow had or did not have the disease in each lactation.

The final statistics calculated at freshening were related to the cow's offspring. Bull calves and twins were simply assigned a market value and sold with corresponding income credited to the cow. Single female calves were assigned a pedigree index that was 22% of the lifetime production of the cow (assumed to be 5 lactations), plus an amount reflecting genetic improvement of sires over time (30 kg/yr). Pedigree index was used as an estimate of the heifer's breeding value, which included genetic plus environmental effects for milk yield. Pedigree index was used to select replacements for the milking herd and as a component of milk yield.

This method of estimation of breeding values illustrates limitations of the model. Pedigree index was a measure of genetic potential of the calf, but was calculated from phenotypic yield of the dam and the genetic value of an "average" sire. The female contribution to the pedigree index implied that cows with higher lifetime yields have offspring with higher breeding values. This is true in general but may not be true in individual cases depending on environmental influences. Similar to previous simulations (62, 63, 77, 78), there was no individual selection and mating of cows and bulls to produce progeny.

Another subroutine was used for calculation of daily milk yield and feed energy consumption. Daily milk yield was calculated from a Gamma function that included effects of age of the cow and days in milk. Included in the estimation of yield were breeding value of the cow, a permanent environmental effect, and the effect of gene segregation, calculated when the animal was selected as a replacement. Temporary environmental effects were calculated as changes in yield due to reproductive disorders, twins, mastitis, and the effect of gestation after the 155th day of gestation. As stated earlier, the effect of mastitis was calculated for clinical cases only. No evidence was found to indicate yield was correlated across lactations for individual cows except through the animal's pedigree index, which included permanent environmental effects for the herd and breeding value.

Daily energy requirements were calculated depending on daily milk yield, maturity of the cow, length of gestation, body weight, age at freshening, and daily weight gain of the cow. Daily energy requirements were dependent on daily yield of the cow in a causal relationship. However, energy intake did not affect yield in a reverse manner, nor was there a way to estimate forage quality or its effect on yield.

Subroutine calls that updated milk yield and feed consumption were made at irregular intervals determined by the occurrence of specific events. In addition to calculating milk yield and feed consumption, this subroutine also calculated and stored feed cost, health cost, fixed costs, body size and growth characteristics, mortality, and determined if drying off or culling was necessary for each time increment. Drying off and culling subroutines will be discussed later.

The subroutine for breeding was called to determine fertility and the probability of conception for cows. Fertility was treated as a discrete event so that 120 d milk yield could be used in calculating days open. This subroutine also calculated breeding cost. Fertility, calculated first, was independent of the number of services required for conception, and was classified as a discrete variable. A cow that required more than four services or had more than 180 d open and was not pregnant was classified as infertile. Infertile cows were culled when dried off. Replacements were procurred when cows were culled or died. Days open were calculated for fertile cows as a function of breeding policy, efficiency of heat detection, milk yield, conception rate, age of the cow, and reproductive disorders or conditions.

Breeding policy was defined as the minimum time in days from calving to first breeding. The effect of milk yield on conception was measured as the deviation of the cow's 120 d milk yield from the average of other cows of the same age. Number of services per conception, which determined breeding cost, were calculated from conception rate and the effect of 120 d milk yield. Services per conception directly affected breeding costs through a fixed cost ($9.38) per service. Individual sire selection was not practiced so there was no variability in price assigned to units of semen. Various breeding policies, conception rates, and rates of heat detection could be set by the operator of the program as model options. No mention was made whether these policies could be set for individual cows. Gestation period for all cows was 280 days, with no variation in length of gestation included in the model. The treatment of days to first ovulation, number of estrous cycles, heat detection program, and breeding programs were more simplistic than those of Oltenacu et al. (63) as Congleton directly estimated days open and services per conception.

Pregnant cows were dried off when daily milk yield was less than 4.54 kg per day, or the cow was less than a specified number of days from her next calving. This was termed the optimum number of days dry and varied according to lactation number and number of days open in the current lactation. Open or infertile cows were sold when their daily milk yield was less than 6.81 kg per day.

Culling occurred through mortality of cows, culling of infertile cows, or culling of fertile cows when they went dry for other than reproductive purposes. Open cows were culled as soon as they were dried off. Additional costs due to health and labor for higher producing cows were added to the total lactation cost at this time. For pregnant cows, a decision was made whether or not to cull the animal for non-reproductive purposes. Cows were culled when their cost per unit of production fell below a level set by the operator. Otherwise, the cow was kept, lactation yield and cost variables were set to zero, and the cow returned to the milking herd file with the next event set as freshening.

Reasons used to identify types of culling were not described in as much depth as either the Oltenacu et al. (63) or Stewart et al. (78) simulations. If a cow was culled, a replacement was selected from the replacement herd, which was stored in a file separate from the milking herd. Replacements were selected on their age and pedigree index value. If the number of replacements was greater than 75% of the number of cows, then replacements of breeding age could be sold. A replacement greater than 395 d old was selected when a cow was culled, and was added to the milking herd when she calved. This appears to be the reverse of what normally would happen on a farm. Usually, the replacement would freshen and then the decision would be made as to which cow to cull. Ninety-one percent of all replacements were considered fertile. Infertile heifers were culled and replaced with other heifers. Date of conception was calculated when the heifer was selected as a replacement. This date was a function of age, conception rate, and percent of heats detected. It was not stated whether the conception rate or rate of heat detection differed between heifers and cows, or by season.

When a heifer was selected as a replacement and conceived, milk yield in the first lactation was calculated in the following manner. A random permanent environmental effect (SD = 421 kg) was created for each heifer. Segregation error (SD = 579 kg) was the variance of heifer breeding values for yield minus one-quarter of the variance of cow breeding values for yield minus the sire variance for fat-corrected Predicted Difference milk yield. Components of yield for the heifer included the pedigree index for yield plus the permanent environmental effect plus segregation error. Temporary environmental effects were added when the heifer was fresh, and accounted for mastitis, reproductive problems, days open, and the effect of gestation. Permanent herd effects were included in the pedigree index. Coefficients of the Incomplete Gamma function (17) were utilized to determine daily milk yield from these factors.

If the heifer conceived, she was placed in the milking herd file with the next scheduled event as freshening. Costs were calculated for replacements by multiplying a constant fixed and feed cost per day times the number of days from birth to freshening. This seems to be a simplification of a realistic replacement program, since these costs are not likely to be constant for calves, yearlings, and bred heifers. Mortality at birth was 5.9% for single calves and 22.4% for twins, and for live heifers was 15% from birth to 15 mo. By dividing the replacement program into segments to account for raising calves, yearlings, and bred heifers, mortality and rearing costs could be more appropriately distributed among the groups. It could not be determined if a growth curve was used to estimate heifer body weights. When the heifer freshened, body weights were assigned for purposes of estimating feed intake and body weight change during the lactation. It would seem desirable to accumulate body weight throughout the lifetime of the animal, particularly if accurate estimates of income and cost over time are needed.

There are many advantages of the Congleton simulation when compared to the simulations of Oltenacu and Stewart. Foremost was the ability of the Congleton simulation to account for many of the biological characteristics and relationships between biological systems of the cow throughout the simulation. The overall dairy management system was covered in more detail by Congleton. The cost of this breadth however, was a lack of depth in areas such as the reproductive programs. Oltenacu et al. (63) looked at the reproductive process in more detail with regard to items such as fertility, conception, the option to apply decisions individually to cows, and reproductive health and disease.

Major disadvantages of the Congleton simulation include inadequacies concerning the replacement program, and calculation of genetic values for animals with possible individual mating of males and females. Improvements in the replacement program could be gained through calculation of breeding values separate from permanent herd effects, and dividing the model into segments for calves, yearlings, and pregnant heifers. Inclusion of growth and cost curves could simulate individual characteristics in more detail than was done. Additionally, it did not appear that management options could be changed at specific times during the simulation.

Validation of the Congleton simulation was performed by executing the model for 30 simulated years. The first 5 yr were used to obtain stabilization, with 25 yr of data collected for statistical analyses. Verification was performed by comparing output from the simulation to two Northeast dairy herd surveys. The surveys evaluated production and economic measurements. Most measures collected from the simulation compared well with survey data. The largest discrepency was for milk yield, where the simulation was considerably higher. Congleton stated this was a result of accumulating the genetic trend of 30 kg/yr over the 30 yr of the simulation, compared with a 2 yr average for milk yield in the survey data. As a result, feed costs and net cash income were higher in the simulation. Reproductively, more replacements were raised per cow, heifers calved about three months earlier, and the rate of reproductive culling was higher in the simulation. The higher reproductive culling was attributed to the culling policy that required more than four services or greater than 180 days open to be classified as a reproductive cull. This policy may be more restrictive than on the average farm. The Congleton model (14) was also used to examine profitability of herdlife (18). The model was updated to include more information on diseases, costs of diseases, and mastitis, and was then used to predict cumulative net income curves for different lactations (19) in a later analysis.

Simulation by Marsh

Marsh and Morris (49) were the first to adapt a large scale dairy herd simulation to microcomputers. The simulation was written in the C programming language and operates on IBM and compatible microcomputers with at least 256 kilobytes of memory. They stated that a herd of approximately 53 cows over 6 yr could be simulated in about 20 min computing time.

A detailed description of the model providing equations and parameters for the simulation has not been published. Limited information regarding model parameters and equations was from later work (48). Equations used to develop most biological relationships were unavailable, although model segments were discussed in sufficient detail to describe the simulation.

The Marsh and Morris (49) model was developed as a generic livestock generator, meaning that parameters of the model could be modified to represent different species of animals. Marsh and Morris (49) described the generic livestock generator, and research of Marsh et al. (48) adapted parameters of the model to represent dairy cattle. Since the model for both papers is similar, references in this review will reflect the work directly involving dairy cattle (48). The model was based on the reproductive cycle of the animal, as were the simulations of Stewart et al. (77) and Oltenacu et al. (63). This assumes that many species of animals have the same basic reproductive cycle, which appears applicable to most farm animals. However, equations that predict growth, milk yield, and feed intake are different across species, and could require considerable effort to adapt the model to a particular species. Use of a species independent model would seem to limit, or make difficult, programming of equations directed only at a single species.

The Marsh et al. (48) model appeared to operate in a similar manner to the simulation used by Oltenacu et al. (63). Events specified in the model were birth, puberty, estrus, conception, gestation, and parturition. Output from the model was calculated daily and summarized annually. Milk yield, reproductive performance, and involuntary reasons for disposal were calculated using probability distributions. Milk yield was calculated using an equation adapted from Oltenacu et al. (63). Calculation of daily milk yield accounted for genotypic production potential, age of the cow, days in milk, and days open in the current lactation. Individual matings were not made, similar to the simulations of Stewart, Oltenacu, and Congleton. Sire selection was limited to genetic trend of sires per year. It was not specified how environmental effects for yield were simulated. Costs for labor and veterinary expenses were calculated on a per cow per year basis, with no relationship to yield of the cow as was done by Congleton (14).

Marsh did not state the maximum number of cows the model could simulate. However, a herd could only be simulated for 6 yr. This seems to be a short time to achieve statistically stable and reliable results, as response of many variables in the model, such as genetic improvement, take a few simulated years to settle into a pattern. The model of Congleton was executed for 5 simulated years to stabilize the model before collecting information for analyses over the next 25 simulated years. Marsh stated the primary objective of the simulation was to develop a teaching aid that could be used in classroom training of veterinarians and for on farm use as a diagnostic tool. Their secondary objective was development of a research tool. This seems to be reflected in the lack of specific relationships between production and reproduction, and in the statistical analyses applied to their culling decision rules.

Input to the Marsh model allowed for more than 100 input variables from seven different categories. The first four categories specified reproductive and productive parameters of the breeding and replacement herd, growth characteristics for replacements, culling rules based on herd size limits and involuntary culling rates, and density functions that determine time to first estrus, time between estrus periods, and time from parturition to removal for culling reasons. The latter three categories specified market values for livestock, determined fixed and variable costs of production, and specified how income taxes were treated.

The ability to have many input variables was a desirable characteristic of the simulation. In many cases the information was input directly rather than determined from information supplied by the user. For example, the rate of heat detection was assigned directly from user input rather than questioning the user on heat detection policies and procedures, and assigning a heat detection rate based on this policy. This type of input would be desirable in instances where one wanted to evaluate different heat detection rates, but might not be representative of realistic relationships between herd reproductive policies and heat detection rate. Marsh stated this simulation was based on the reproductive cycle of the cow, but assumes no relationships between reproductive and productive variables, in contrast to the simulations of Congleton (14) and Oltenacu et al. (63). A positive aspect of the Marsh simulation was that it could stop at the end of each simulated year to generate reports or update parameters.

Marsh used the simulation to evaluate effects of different culling policies on profit of individual cows. Four culling policies were used. Two policies included no breedings after a fixed number of days open (165 d and 250 d), and remaining policies included combinations of a milk yield index with the number of days open. The four policies were compared at nine combinations of detection of estrus and conception rate to identify interactions of culling policy with reproductive performance. Marsh determined that profits were maximized when culling policies were not too restrictive. This was reasonable since improvement in reproductive performance brought about by improved management practices should be more profitable than improvement in reproductive performance by more restrictive culling. Culling policies that used a milk yield index and the cow's reproductive status were especially useful if detection of estrus was poor.

The work of Marsh was an extension of research on culling decisions by Dijkhuizen et al. (24) for Dutch dairy herds. Although culling decisions including productive and reproductive information were more detailed in the Marsh model than in the models of Congleton (14), Oltenacu et al. (63) and Stewart et al. (77), there appears to be a lack of depth in relationships between production and reproduction that could limit its effectiveness as a research tool.

Simulation by Dijkhuizen

Dijkhuizen et al. (24) developed a simulation for Dutch dairy herds in 1986. The simulation was written in the Fortran-77 programming language, designed to operate on either mainframe or minicomputers. The simulation could create any number of herds with up to 100 milking cows plus youngstock in each herd over a period of 15 yr. The first 5 yr of output from this simulation were used for stabilization of the model, with the remaining 10 yr of data collected for statistical analyses. Variables were calculated daily within 20 d periods. It was not stated if changes in options could be made during the process of the simulation.

Milk yield, fat percent, protein percent, reproductive performance, and involuntary disposals were calculated using probability distributions. This was the first simulation to incorporate protein yield into the model. Deterministic variables were feed intake and cost, body weight, and number of youngstock. Their primary interest concerned reproductive performance and culling decisions, similar to previous research, with little mention of the youngstock program other than the calculation of breeding values for heifers. Once again, sire selection was limited to genetic progress per year (63 kg) and individual matings of cows and bulls were not performed.

Some features of the Dijkhuizen model were not applicable to operation of U.S. dairy farms, such as grassland management and the milk pricing system. However, these are not directly related to calculation of productive or reproductive performance and should not have an effect on technical aspects of the model.

Milk yield for individual cows was calculated from lactation curves. Fourteen lactations each with 10 calving intervals from 340 to 520 d were used. Previous simulations (14, 49, 63) have used lactation curves for first, second, and later lactations only. Length of calving interval was accounted for in some of these models (14, 63) by including an effect of days open or days pregnant on milk production, essentially the same as was done by Dijkhuizen using the current calving interval rather than days open. Deviations from lactation curves were assigned to account for breeding value of the cow, permanent environmental effects, temporary environmental effects, a short term effect for each 20 d period, and an effect for the previous calving interval. The temporary environment for milk production changed for each lactation of the cow. The short term effect for milk production changed for each 20 d period, and was correlated with the past two 20 d periods for continuity of the model. This was the only simulation that had attempted to do this.

Short term effects were calculated for milk yield only, and were limited to 25% of the value of the lactation curve. In the current lactation the effect of days open on milk yield was accounted for by inclusion of the calving interval. An effect of days open in the previous lactation was included through the previous calving interval. The effects of days open on production, both in the current and previous lactations, cover the subject more thoroughly than previous simulations. There was no seasonal variation calculated for milk yield or other variables.

Breeding values were assigned to calves at birth, calculated as one half of the sire's plus the dam's breeding value, plus a segregation effect of genes. Nutrient intake was calculated for milking cows, and will be discussed later. It was not stated if growth functions or nutrient intake were calculated for youngstock. Heifer rearing was not given much consideration in this model. When replacements were added to the herd, there was a fixed charge of 2400 Guilders (about $1200) per heifer, regardless of whether the heifer was raised or purchased as a replacement. This charge also did not reflect differences in size or production potential of heifers. Guilders will be represented by the term Dfl. for the remainder of this paper.

Parameters used in the calculation of milk, fat, and protein yield were a heritability of .25, a repeatability of .5, and a coefficient of variation of 15%. Genetic and environmental correlations of milk yield with fat percent were included as weighting factors in prediction of fat percent. Similar correlations of milk yield and fat percent with protein percent were included as weighting factors in the prediction of protein percent. Correlations were based on actual yield measured as deviations from the herd average for this purpose. Yield variables calculated were daily milk yield, mature equivalent milk yield, 305-day fat and protein production relative to the herd average, and Cow Indexes for milk, fat, and protein.

Data concerning reproductive performance during the lactation were calculated at the time of calving. Reproductive performance was calculated as a function of time to first estrus, heat detection rate, and probability of conception. Time to first estrus was based on calving problems of the cow, cows with calving problems having a longer time to first estrus. It was assumed 11.4% of all cows had calving problems, not distinguished among two year old heifers and older cows. This would imply that increased calving problems were not assigned to two year olds in this model. Individual reasons for calving problems were not provided as done by Congleton (14). One overall heat detection rate for the herd was set by the operator of the program. Probability of conception for a given service was dependent on age of the cow, type of parturition (normal versus abnormal), time of first breeding, and number of breedings.

All gestations were assumed to be 280 d in length. Breedings could take place from 60 to 240 d after calving. Cows not bred after 240 d were culled at the end of their lactation. The operator could set the policy concerning whether or not to cull a cow. For example, in this simulation the breeding policy was set as follows: Cows with relative production less than 80% of the herd were not bred, cows with relative production between 80 and 90% were bred up to a maximum calving interval of 440 d (maximum 160 d open), and cows with relative production greater than 90% were bred up to a maximum calving interval of 520 d (maximum 240 d open). Dijkhuizen termed this policy "strategic breeding."

For the youngstock program, sex and viability of calves were determined at calving. Mortality rates were 4% for calves less than 24 h old, 2% from 24 h to 1 wk, and 5% from 1 wk to breeding. There was no mention of whether twinning was estimated, so it was assumed included in the 11.4% calving problems. Number of replacement stock needed was based on the average replacement rate for the previous 5 yr, and was equally distributed over each 20 d period per yr. The number of female calves kept as replacements was equal to the number needed in that period if enough were available. This figure could be adjusted for a shortage in any of the five previous 20 d periods if excess heifers were available. If excess heifers were still available after replacement requirements were met then heifers could be sold, retaining heifer calves with highest estimated milk income. All bull calves were sold at birth.

Heifers were bred beginning at 14 mo of age continuing until 21 mo old or pregnant. It was assumed 5% of these heifers were sterile and were subsequently culled. The number of heifers ready to calve and enter the milking herd was calculated, and if this number was excessive, culling was performed in the following manner: It was determined if culling of cows could be done prematurely (i.e., within the next two months). If premature culls were available, they were culled first. If no premature culls were available, bred heifers with the lowest estimated milk income were sold. If there were not enough springing heifers in the herd to provide an adequate number of replacements to maintain the milking herd, replacements could be purchased at the same price at which they were raised. It was not stated how purchased animals were created, or if they were genetically and environmentally equivalent to animals currently in the herd.

Voluntary culling of cows using the decision process of the model included culling for low production and failure to conceive. Culling for failure to conceive was considered a voluntary decision in this model. All other culling reasons were considered involuntary, and were not specified individually as done by Stewart et al. (77). Involuntary culling depended on age of the cow and stage of lactation. Generally, involuntary culls were highest at calving, dropping to a low frequency from approximately 30 to 150 d after calving, and gradually increasing during the remainder of the lactation. Probabilities of culling later in lactation were adjusted for different lengths of calving interval. Cows that survived through 14 lactations were culled because of old age. Different rates of involuntary culling were specified for cows of different ages, from 11.8% in the first lactation to 32.5% in the 14th lactation. For cows not culled it was not specified if age had an effect on calving problems.

Sixty-five percent of involuntary culls were related to problems at the time of calving, and the remaining 35% of culls were distributed throughout the lactation and were randomly selected. It was not stated if this proportion varied by age, which would be necessary to account for dystocia problems in first lactation heifers. When cows were culled, they were charged for costs representing reduced milk receipts, veterinary treatment, and drugs. These costs ranged from 295 Dfl. (about $148) in first lactation animals to 500 Dfl. (about $250) in 14th lactation animals. Involuntary culling of youngstock was 5% up to 6 mo of age, 2.5% from 6 to 12 mo, and 2.5% from 12 mo to calving. It appeared this was in addition to removals for death and infertility.

Deterministic variables, those calculated directly from values of other variables without using probability distributions, were feed intake and cost, body weight, calf and carcass value, and fixed costs not directly related to cattle (i.e., cost of buildings and equipment). Feed intake was calculated through energy requirements only, with no consideration given to protein content of feeds or other measures of feed quality. Energy intake was expressed in Dutch Feed Units for lactation, so the equations used by Dijkhuizen may not be directly comparable to U.S. equations for energy intake. Also, energy requirements for intake were calculated as the average of feed intake for feeding cows inside and grazing cows on grassland. Grazing lactating cows primarily for the purpose of nutrient intake is not common in the U.S., nor is grassland managed as intensively as in The Netherlands. Comparisons between these two systems of feeding between countries are difficult for these reasons.

Energy requirements were calculated daily and depended on the metabolic body weight of the cow and her daily fat corrected milk yield. Metabolic body weight is actual body weight raised to the .75 power, and has been shown to be a better indicator of energy intake than actual body weight. Actual body weight was calculated at calving as a function of the cow's age and mature body weight of the breed (600 kg). Maturity factors were included to estimate weight for different calvings. Body weight of the cow was allowed to change (i.e., decrease and then increase) during the lactation. Body weight could increase up to a fixed point which was the beginning weight for the next lactation.

Changes in body weight were determined by intake capacity and energy requirements of the cow. Intake capacity of the cow was estimated in kg per day based on breed, milk and fat production, body weight, and stage of lactation using the equation of Kuipers (42). Roughage and concentrate proportions were calculated to allow for a physical ration structure sufficient for fermentation, as was done by Kuipers and de Jong (43). Energy content of forages and concentrates differed, but only a single value was available for each type of feed. This implied different forages could not be used at the same time in a ration.

If the energy requirement of a cow was greater than the energy available through intake, she could lose weight until she reached 87.5% of her weight at calving. If the animal still required more energy than she could ingest at this minimum weight, her milk yield would decrease. While the cow was losing weight, this loss was converted to energy for milk production at 80 to 90% efficiency. When intake capacity for energy of a cow exceeded the energy requirement for milk yield and maintainence, the cow could gain weight. Maximum gain was restricted to 1.25 kg/d, and maximum total gain during the lactation was limited by the beginning weight for the next lactation. There was an additional effect of weight gain calculated due to the length of the calving interval, which was stored separately and could be used for conversion to milk production in the following lactation. Feed costs were determined directly from intake of forages and concentrates.

Income from sales of calves were determined by sex of the calf and age of the dam, with calves of older cows being more valuable. Mortality rates were higher for calves of first lactation heifers than for older cows. Carcass value of cull cows was dependent mainly on body weight, although older cows were discriminated against through lower dressing percentage, which was included when assigning salvage value to cull cows. Dressing percentage was calculated daily based on the beginning dressing percentage for a lactation plus a stage of lactation effect, which also influenced carcass value.

Fixed costs not directly related to cattle for buildings, machinery, etc., were included to estimate realistic levels of net income per cow. These fixed costs had no effect on culling decisions. Interest was charged on cows depending on market value and age. Veterinary costs were charged to cows based on stage of lactation so that 25% of total veterinary cost was assigned in the first 20 d of lactation, 25% was assigned in the following 2 mo, with the remaining 50% assigned during the rest of the lactation. It appeared that total veterinary costs for a lactation were assigned at the beginning of a lactation, and not specifically on occurrence of a health related event, such as mastitis.

Dijkhuizen used sensitivity analysis to evaluate the response in simulation variables to changes in model parameters. Each model parameter was evaluated at a base value and subsequently increased and decreased from this value. Parameters were changed one at a time, so interactions between different parameters were not measured. Parameters that changed (original value ± change for sensitivity analysis) were estrus detection rate (70% ±20), calving rate after first breeding (60% ±20), breeding and culling policy (stated earlier as strategic breeding, + was all cows bred to a maximum calving interval of 520 days, - was all cows bred to a maximum calving interval of 360 d), initial mature equivalent herd average milk yield (6275 kg ±1000), genetic trend (63 kg/yr ± 63), involuntary disposal (index = 100 ±20), cost per springing heifer (2400 Dfl. ±250 ($1200 ±125)), and maximum daily roughage intake of DM (10 kg/cow/d ±2). Maximum roughage intake of 10 kg/d seems unreasonably low.

A base situation was run with all model parameters at their original value. Sensitivity analyses were performed on one variable at a time by raising and then lowering the parameter from the original value. Deviations for each parameter were not standardized for normal variation, so response of output variables was not on an equivalent basis. Thus, it was difficult to rate the importance of each parameter relative to others.

The major variable measuring model performance was net return to labor and management, measured in Dfl./cow/yr. The three parameter changes resulting in the largest increases in net return/cow/yr, compared to the base level, were an initial increase in mature equivalent herd average milk yield of 1000 kg (+392 Dfl./cow/yr), raising genetic progress of sires 63 kg/yr (+146 Dfl.), and raising daily roughage intake 2 kg/cow/d (+96 Dfl.). The three parameters resulting in the largest decreases in net return, again compared to the base level, were a decrease in initial mature equivalent milk yield of 1000 kg (-421 Dfl./cow/yr), a strategic breeding policy requiring all cows to have a maximum calving interval of 360 d (maximum 80 d open) (-282 Dfl.), and genetic progress of sires reduced by 63 kg/yr (-153 Dfl.). Of all of these changes, the one concerning strategic breeding seems the most extreme relative to normal herd management procedures.

Dijkhuizen found small differences in net return based on changing heat detection rates or calving rates only, which for all changes were less than 35 Dfl./cow/yr. This was similar to results found by Marsh et al. (48) and could be attributed to the small consequence of changing estrus detection rate or calving rate without a restrictive reproductive culling policy.

The Dijkhuizen simulation does an excellent job of accounting for situations that create biological variability in real life. Many of the more important relationships included in the model represent improvements in simulations developed by previous authors. Improvements in this simulation could be made through the addition of individual matings of cows and bulls, and by improving relationships of feed intake with milk yield to include protein and energy content of the ration along with quality estimates of feeds. Greater detail in youngstock programs would also be beneficial.

Van Arendonk (86) has also developed a dynamic programming model to estimate net revenues and the course of income and expenses during the lactation for Dutch dairy cattle. His model appeared to include many of the same relationships as the model used by Dijkhuizen et al. (24). The programming language used and computational facilities required to run the Van Arendonk (86) model were not specified. Milk yield was predicted differently by Van Arendonk, as he used a single equation to predict milk yield rather than using 14 lactations, as done by Dijkhuizen et al. (24). The model segment estimating energy requirements was similar between the two models. The Van Arendonk model included relationships of milk yield with fat and protein percent within lactation, which was not done by other researchers. It appeared that cows were not moved through time with the dynamic programming model of Van Arendonk. Rather, comparisons were made across lactations based on information from different cows. Results of this model will be presented later in the section concerning profitability.

Toro Heifer Simulation

It has been noted that simulation of heifer rearing practices has been given little or no consideration by previous authors (14, 24, 48, 63, 77). Although some simulations assigned breeding values to heifers, they did not consider growth and cost functions for rearing heifers. Also, they did not consider that heifers could be raised under different management systems and at different costs. However, Toro (85) developed a simulation for rearing dairy heifers that specifically considered these problems. The Toro (85) program was written in the Q-GERT (Queueing - Graphical Evaluation and Review Technique) simulation programming language, designed for use on mainframe computers. It made extensive use of Fortran subroutines.

The Toro simulation did not utilize matings of cows and bulls to create calves, but created them directly through simulation. Breeding values for calves were not considered in the model as the simulation ended at first calving, thus milk production was not simulated. The purpose of the model was to quantify costs of raising heifers under different management systems. Genetic ability for milk production and growth characteristics of the sire and dam were not simulated, so the model assumes no relationships between these factors and growth of the heifer. Management options for raising heifers included all combinations of two ages at weaning, three breeding strategies, three growth curves, and three percentages of energy intake from pasture. Output concerning costs and growth factors for different management situations could be incorporated into heifer rearing practices of a new model to more accurately estimate heifer rearing costs.

Genetic Simulations

Another component not considered in simulations of previous authors was mating cows and bulls to produce calves. Calves were produced from cows in these simulations, but rather than using individual bulls for matings, a single bull was used that usually represented the average genetic progress in milk production per year. Because of this there was no variability in milk yield or reproductive traits due to sires within years, unless these models were run several times with variation included for sire parameters. Although this type of mating scheme was sufficient to create animals for use in these simulations, this type of procedure leaves no opportunity for the study of mating programs or selection on traits other than milk yield. The simulations of W. R. Harvey, L. D. McGilliard, and R. L. Willham used for teaching breeding principles did allow individual matings to be made. An additional simulation that considered individual matings of cows and bulls was developed by McGilliard and Edlund (51) to study consequences of using different breeding strategies. Their program was written in Fortran, designed for use on mainframe computer systems.

The major advantage of the McGilliard and Edlund (51) simulation was that individual matings were made between cows and bulls. Resulting offspring were assigned breeding values for production traits calculated as one-half of the sire's plus the dam's breeding value, plus an effect of gene segregation. Randomly selected permanent and temporary environmental effects, both for herds and individual cows within herds, were included to produce realistic values for milk yield, fat percent, solids-not-fat percent, and final type score. This was the only simulation to consider type score of the cow in the calculations. Several genetic and environmental evaluations were calculated that could be used for culling decisions or selection. Involuntary culling was based on probability distributions. Voluntary culling was performed by the operator at the end of each year based on the value of any available variables.

The operator of the McGilliard and Edlund simulation could set parameters such as the mean and standard deviation for production traits; variability for herds, permanent environment, and temporary environment; and phenotypic, genetic, and environmental correlations for production traits. Herds were updated yearly based on mating decisions made by the operator. Decisions were to select service sires, cull cows and/or heifers, and save bull calves.

A disadvantage of this simulation was that matings to only one bull could be made per year. Also, cows were not assigned a number of services required for pregnancy, but were listed simply as pregnant or open. Open cows were calculated as a percentage of all cows from probability distributions, so heat detection programs and the probability of conception were not treated the same as in other simulations. There was no policy to cull open cows, so if a cow did not conceive she was kept until the next year when the operator could make the decision to cull the cow. There was a relationship between milk yield and the probability of remaining open included in the model equations, but not strictly in the sense of creating higher days open as was done in other simulations. Similar to other simulations, there was no heifer rearing program included although heifers could die, be culled, or be bred at each yearly interval. Reproductive problems were not considered in as much depth as in simulations by other authors.

All of the simulations reviewed in this paper, with exception of the Marsh et al. (48) simulation, were designed for use on mainframe computer systems or minicomputers. Only the Marsh et al. (48) simulation was designed to operate on a microcomputer. The growing popularity of microcomputers, combined with increases in speed of computation and amount of memory available, make the microcomputer a logical choice to perform simulations in the near future. Major problems in the past that have prohibited development of simulations on microcomputers have been minimized.

Recently, Yerex and Van Vleck (93) have developed a microcomputer simulation designed to evaluate selection principles in a teaching environment. At the present time, information on the simulation is in abstract form only, and is understandably incomplete with reference to equations used for calculation of values representing animals. Their program operates on IBM and compatible microcomputers with at least 320 kilobytes of memory. The maximum herd size was 120 animals, of which 40 can be milking cows.

Management decisions in the Yerex and Van Vleck (93) simulation were included in "packages" which could be "purchased" by the operator. This implies that individual management decisions could not be made. Output from the model included herd and individual animal data, printed at the end of each year of the simulation. Mating decisions, and the decision to purchase a management package could be made yearly. The time increment for calculating milk yield was not stated, although it appeared yearly mature equivalent milk yield was calculated. Type score for individual animals was also calculated, however, no milk components were estimated with the model.

A similar microcomputer simulation has been developed (73) to evaluate genetic principles for instructional use. This simulation operates on IBM compatible and Macintosh personal computers. The simulation contains quantitative and qualitative genetic effects, lethal genes, production traits, and type traits. The Shook et al. (73) simulation was the first to incorporate linear type scores and somatic cell count information for individual cows. Options allow the operator to employ techniques of embryo transfer and freezing. Individual matings can be made in the simulation.

Factors Affecting Profitability of Dairy Cattle

Profitability, accumulated over all cows in a herd, is imperative to survival of the dairy enterprise. Several authors have investigated various aspects of profitability of cows using simulated data (1, 15, 16, 18, 19, 36, 64, 65, 86, 87), research data (8, 35), and field data (5, 6, 83, 84). Data from simulation and research herds are desirable when estimating profit because of their completeness, accuracy, and usually long period of collection. Field data are more difficult to interpret because they normally lack completeness and accuracy, although field data have importance because of the direct connection to the dairy producer. Evaluation of research related to profitability of dairy cattle will be approached as it pertains to factors evaluated in the present study. As such, research applicable to profitability of herd and cow production, sire selection, culling, calving difficulty, and heifer rearing will be reviewed.

Culling is a major factor affecting profitability of cows. It is important because cows that are culled no longer have the opportunity to return profit to the enterprise. On a herd basis this implies that cows remaining in the herd must return profit, offsetting expenses incurred by themselves and cows that left the herd. Involuntary culling is defined as cows leaving the herd for reasons beyond control of the farm operator. Removal for death, disease, and infertility are examples of involuntary culling. Voluntary culling is the result of a conscious decision by the farm operator to remove an animal that otherwise would remain in the herd. Sales of excess or unprofitable cows are examples of voluntary culling. In either situation, culling removes some animals from the herd, meaning the remaining animals must offset expenses of all cows before a profit can be realized. Involuntary culling in the purest sense cannot be changed, and thus implies a specific income and expense structure for cows that leave the herd. However, voluntary culling is performed at the discretion of the farm operator, and can change the structure of income and expenses, and therefore profit of the farm.

Several authors have investigated the effects of culling on profit of cows and herds (1, 2, 15, 22, 24, 48, 63, 77, 88). Some of this work has been reviewed in previous sections. Freeman (33) also reviewed work of several authors with respect to culling and its relationship with management goals of dairy producers. Dentine et al. (23) found that grade cows left herds approximately 2.9 mo earlier than registered cows. Length of herdlife of all animals was related to PD milk of the cow's sire, but was related to PD type only for registered cows. Dentine et al. (22) determined that grade and registered cows left herds at different rates and for different reasons. Grade cows left herds 3.3% less for dairy purposes, but 1.3% more for low production, 1.1% more for mastitis, 1.1% more for disease or injury, and .6% more for reproductive problems. Allaire et al. (2) identified that functional priorities change as age of the animal changes. Starting with birth, most important priorities were calves that were free from disease, heifers that had the ability to reproduce, first lactation heifers that produced milk above a minimum level, the ability to sustain production over several lactations, a continuous low incidence of mastitis, and good general health. Cows were removed for reproductive purposes most frequently from 24 to 36 mo of age, for production from 36 to 48 mo, for mastitis from 60 to 72 mo, for type from 24 to 36 mo, for health at older than 120 mo, and for milking characteristics from 48 to 60 mo. Heifers were removed most frequently for disease at younger than 5 mo, for type from 6 to 15 mo, and for reproduction from 16 to 24 mo.

Much research has been devoted to evaluation of profit as level of milk yield changes. Van Arendonk (86) estimated cow revenues at 6 to 8 yr of age were 963 Dfl. higher than revenues for first lactation heifers. This value included 1323 Dfl. increased milk receipts, 60 Dfl. increased calf receipts, 410 Dfl. increased feed expenses, and 10 Dfl. increased sundry expenses. Carcass values also influenced profit, and were maximum for 5 yr old cows in month 7 of lactation. Carcass values for these cows were 194 Dfl. higher relative to first lactation heifers. Older cows (7 yr) produced more milk than first lactation heifers, and increased 38 Dfl. more in profit as they increased from 70 to 130% of herd average production than first lactation heifers with similar increases. Longer calving intervals were associated with declining monthly net income. Average revenue was lowest for cows freshening in April, mainly due to the seasonal effects for production, which were lowest in that month. Van Arendonk (88) reported future projected profit for cows by lactation, month within lactation, and relative milk yield. He found that cows milking 114% above herd average production in the third lactation had higher future projected profit in the month of lactation with lowest projected profit (month 9) than cows milking at 84% of herd average production in the month of their highest projected future profit (month 1).

Tigges et al. (83) predicted profit and profit per day for cows from a relative net income function based on information collected by DHIA. They determined that relative net income could be used successfully to predict lifetime profit. The amount of variation explained by the model including relative net income was larger for total profit (95%) than for profit per day (85%). In a later study, Tigges et al. (84) predicted lifetime relative net income from first lactation production and type traits. Significant effects included the cow's final score, first lactation production, days in milk when classified, and herdlife opportunity. Factors in the model explained 12% of the variation in lifetime relative net income. Individual type traits affecting lifetime relative net income were mainly udder characteristics.

Gill and Allaire (35) reported that maximum profit was associated with age at first calving of 25 mo. To maximize herdlife, the optimum percent of days open and days dry over the cow's lifetime were 32 and 10.5%. Age at first calving of 22.5 to 23.5 mo was related to maximum total lifetime performance. Profit per day of herdlife was more closely related to herdlife (R^2 = .628) than milk per day of life (R^2 = .352). Allaire (1) stated that to minimize costs, it was necessary to keep a high proportion of mature cows and have a low replacement rate rather than raising excess heifers and culling low producers in first lactation. This was because of the relatively high cost of raising replacements. Culling 0 to 3 cows per 100 total cows maximized herd net present value, and culling 10 to 15 cows per 100 total cows maximized milk yield per cow per year.

Using an earlier simulation (14), Congleton and King (18) evaluated the profitability of herdlife in dairy cows. Cows were culled on cost per unit of production. Herdlife was extended on cows by reducing the voluntary culling criteria. A .5 increase in number of lactations (from 2.8 to 3.3) resulted in more days open, lower annual milk yield (-36.6 kg), lower replacement costs, $19.45 less cull cow income, and $1.03 greater health costs. However, increasing herdlife from 2.8 to 3.3 lactations increased annual income $29.92 and discounted income $314.52, presumably through lower replacement costs. Higher salvage values and lower total feed prices decreased profitability of extending herdlife. Lifetime income per cow increased approximately $700 as herdlife was extended from 2.6 to 4 lactations. In 1987, Congleton and Roberts (19), also using the updated model of (14) estimated the cumulative net income of cows with a second order equation. They found prices of feed and milk, breeding value, and health disorders affected the linear coefficient of the equation and thus represented a cumulative effect over the entire lactation. The quadratic coefficient was most affected by days open and infertility. The point of maximum income was 32.2 wk for first lactation cows, increasing to 35.8 wk for cows in lactation 4 and greater. They suggested culling of young cows should be performed earlier in lactation than culling of older cows.

A study by Congleton et al. (16) showed that uniform annual cash flow peaked in the second lactation at +$310, was relatively constant for lactations 2 to 5, and decreased to +$248 by lactation 9. Congleton (15) noted that culling based on projected income increased herd income by 4.3 to 4.8% compared to culling based on age adjusted production over a 20 yr planning horizon. Breeding the highest producers and culling infertile cows at their peak income increased herd income from 4.3 to 5.7% over 20 yr compared to breeding all cows and culling the lowest producers when heifers freshened. Culling on projected income decreased genetic trend from 65 to 86% because older cows were kept in the herds instead of replacing them with genetically superior heifers.

Van Arendonk (87) stated that a proportional reduction in involuntary culling of 40% would allow for increased voluntary culling of 18%, an increased financial advantage of 85 Dfl., and would increase herdlife 7%. A 20% increase in sire PD milk resulted in 10 mo greater herdlife, although he noted that selection on milk yield did not necessarily increase herdlife. Herdlife decreased 1.5 mo and income increased 372 Dfl. as herd average milk yield increased from 6500 to 7500 kg. Pearson and Freeman (65) evaluated effects of female culling and herd age distribution on profit. They determined that rearing costs, genetic progress, and milk yield affected profit in different amounts and under different conditions over 20 yr. Raising fewer replacements was profitable even with low yield because of the lower cost associated raising fewer replacements. With low rearing costs, profit was proportional to milk yield. Profit was greater in larger herds because of lower fixed costs on a per cow basis.

With respect to sire evaluations, Beaudry et al. (5) calculated sire evaluations for relative net income for individual daughters and groups of progeny of AI sires. They reported small effects of sires on deviated relative net income when individual daughters were evaluated. Evaluations were more accurate when progeny groups of sire's daughters were used. Coefficients of model parameters were larger when PD dollars were included in the models. Prediction of progeny group averages for lifetime relative net income was superior to prediction of relative net income per day for progeny groups. Beaudry et al. (6) evaluated the effect of changing prices on a profit function, and concluded that changing prices affected the mean and standard deviation of profit. Correlations between different measures of profit were greater than .95. They concluded that relative net income data were relatively unaffected by changes in prices if the prices used in the estimation of relative net income were reasonably accurate.

Bertrand et al. (8) investigated differences in profit of daughters of sires grouped into high versus average PD milk. They reported daughters of high PD milk sires were 18% more profitable. More profitable cows had 16% more milk and 21% more total costs. Components of increased total costs were 9% higher feed costs, 49% more semen costs, 42% more discarded milk, 26% increased mammary costs, 9% more respiratory costs, 6% more digestive costs, and 8% more skin and skeletal costs. Reproductive health costs, number of breedings, and number of reproductive exams were not different between the groups.

Another factor related to profitability in cattle is dystocia, or calving difficulty. As a consequence of dystocia, cows generally have higher reproductive health costs, more reproductive problems, produce less milk, take more time to return to normal cycling activity, and exhibit lower conception rates and sterility. Calves born from cows with dystocia have higher mortality rates at birth. All of these factors represent lost income to the producer, and thus lower profit. Several authors have evaluated the effects of dystocia. These include work regarding sire evaluations for dystocia (7, 25, 70, 90, 91), cow evaluations and maternal effects for dystocia (81, 82), and consequences of dystocia on birth weight, stillbirth rate, production, and reproduction of cattle (26, 58, 66, 67, 68, 69). Stevenson and Call (76) reported an overall dystocia incidence of 5.8% in their review of reproductive disorders.

Philipsson (69) noted that costs due to dystocia were due to lost calves, securing replacements for cows, extra inseminations, veterinary treatments, labor, and miscellaneous costs. The percentage of cows slaughtered at calving increased 3.4% when dystocia occurred. Cows that had a difficult birth had 7.1% more culling in their first lactation, were 10.2% lower in conception rate at first service, and had 10.4% more retained placentas. Djemali et al. (26) listed costs associated with an occurrence of dystocia as $14.66, which included losses due to milk and fat production, and lost calves. Toro (85) estimated losses due to a case of dystocia in first lactation heifers at $48 (from McDaniel), which included a visit and treatment by a veterinarian, but did not include lost milk and fat or lost calves. Djemali et al. (26) reported that cows with dystocia had increases of 14, 26, and 19 d open in lactations 1, 2, and 3 and greater. Decreases in production due to dystocia were 465 kg ME milk in lactation 1, 576 kg ME milk in lactation 2, and 725 kg ME milk in lactations 3 and greater, although the incidence of dystocia is lower with increasing lactation number.

An important factor affecting dystocia was size of the calf, as measured by birth weight within breed. Other factors related to dystocia, such as gestation length of the dam, sex of the calf, and sire of the calf, were at least partly related to weight of the calf at birth. Philipsson (66) reported male calves at birth were 3 kg heavier than female calves (44 vs 41 kg). In a beef cattle study, Notter et al. (58) found that Jersey crossbred cows had the lightest calves (31 kg), shortest gestation length (282 d), least dystocia (17.5%), and lowest calf mortality (6%). Brahman sired calves were heaviest (35.3 kg), had longest gestation length (289 d), had most dystocia (67%), and had highest calf mortality (21%).

Size of the calf was not the only factor related to dystocia. Philipsson (66) noted an effect of sex of the calf after birth weight had been adjusted, accounting for 5% of the variation in calving difficulty. He also stated that pelvic size of the dam accounted for 10% of the variation in calving difficulty. Abnormal presentations of calves represented 5% of all births and accounted for 20 to 30% of all dystocia, regardless of calf birth weight. Male calves were twice as likely to be abnormally presented than female calves. Philipsson (66) found that 40 to 60% of all dead calves were a result of difficult calvings.

Another factor affecting dystocia was the relationship of calf birth weight to cow body weight, which Philipsson (67) reported to be more favorable in cows than in first lactation heifers. This was because there was a larger increase in cow body weight as a cow matures relative to the weight of her calves. Philipsson stated that age at first calving was not important with respect to calving difficulty between the ages of 26 to 33 mo, and only slightly important at other ages. Birth weight of calves increased only .1 kg/mo of age at first calving. Birth weight increased .2 to .4 kg/d of gestation length in another study (68). For male calves, Philipsson (67) reported 9% dystocia when calves born weighed less than 35 kg, with dystocia increasing from 9 to 60% as calf birth weight increased from 35 to 50 kg. Response was similar but smaller for female calves.

Distributions used for Simulation of Biological Variability

Simulations use probability distributions to generate numbers that represent biological characteristics and variation of individual animals, groups of animals, and herds.

Equations for some of the more commonly used distributions will be presented, noting the impact of changing parameters of the distributions.

A simple, but very important distribution utilized in simulation is the Uniform distribution. The distribution is generally defined as any single value in a range of many values having equal probability of selection. For a minimum value a, a maximum value b, and with n points in the b-a range of the Uniform distribution; the probability of selecting a specific point is $\frac{1}{n}$, the mean is $\frac{a+b}{2}$, and the variance is $\frac{(b-a)^2}{12}$. Figure 1 shows a Uniform distribution of 10 points that are between the values 0 and 1. Each point has a 10% probability of being selected. Mean and variance of the distribution are .5 and .0833, respectively. As the number of selectable points in the range increases, the probability of selecting a specific point decreases.

Uniform random numbers are defined as decimals with equal probability of occurrence between 0 and 1. Importance of the Uniform distribution and Uniform random numbers is in two major areas. First, simulating the occurrence of events that are distributed by percentages. In the simplest case this is prediction of Binomial occurrences. For example, when a cow is bred she either becomes pregnant or remains open with specific probabilities that sum to 1. If the cow has a 70% chance of becoming pregnant then she has a (1-.7) or 30% chance of being open. Since Uniform random numbers are equally likely, a simulation will select a Uniform random number, and if the number is less than .70 then the cow is declared pregnant. This concept can be expanded to more than two occurrences where the probabilities sum to 1, or the probabilities sum to less than 1 but can be adjusted to sum to 1. Uniform random numbers are used to simulate the distribution of calvings in a herd, sex of newborn calves, probability of contracting a disease, determination of estrus, and many other factors. The second important application of Uniform numbers is to create numbers representing other distributions. Using groups of Uniform numbers to create numbers from the Normal distribution is

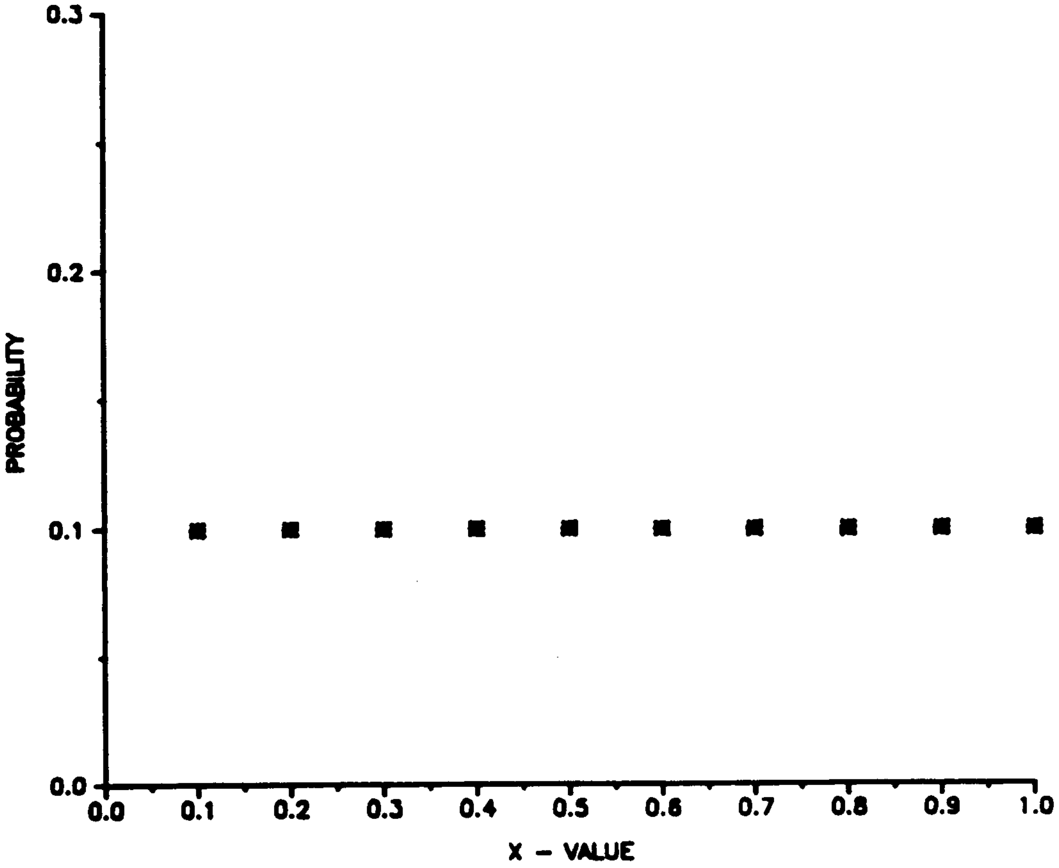

Figure 1. The Uniform distribution.

probably most important in microcomputer applications. For example, the sum of 12 Uniform random deviates minus their expected mean (6) will be distributed normally with mean 0 and SD 1.

The most common distribution used in simulation of biological characteristics and variation of individual animals is the Normal distribution. It is frequently used because variability involving individual cows, cows within a herd, and differences between herds are normally distributed. This implies values are as probable below as above the mean. For example, lactation yield for all cows in a herd is normally distributed about the herd mean for yield, as are breeding values for sires of cows within herd. These two relationships are similar, but not equivalent because each biological characteristic has a different mean and different variability about that mean.

An unlimited number of Normal distributions can be generated from the Standard Normal distribution, that is a Normal curve with mean 0 and SD 1. Standard Normal deviates are values that represent the number of standard deviation units the value deviates from the mean. The Standard Normal curve is shown in Figure 2. Standard Normal deviates can be positive or negative, determined by whether they are greater than or less than the mean. A Standard Normal deviate can be transformed to a number sampled from any Normal distribution of mean x and SD y simply by multiplying the deviate by y, and adding that result to x. For a desired biological characteristic, if the mean and standard deviation are known and the distribution is assumed normal, this simple mathematical conversion can be used to create values that represent deviations from the desired biological mean using the Standard Normal distribution.

Not all relationships involving biological variability are normally distributed. An example of a biological characteristic of cattle that is not normally distributed is daily milk yield of a cow during her lactation. Milk yield usually starts at a low value, peaks at about day 45 of the lactation, and gradually declines for the duration of the lactation.

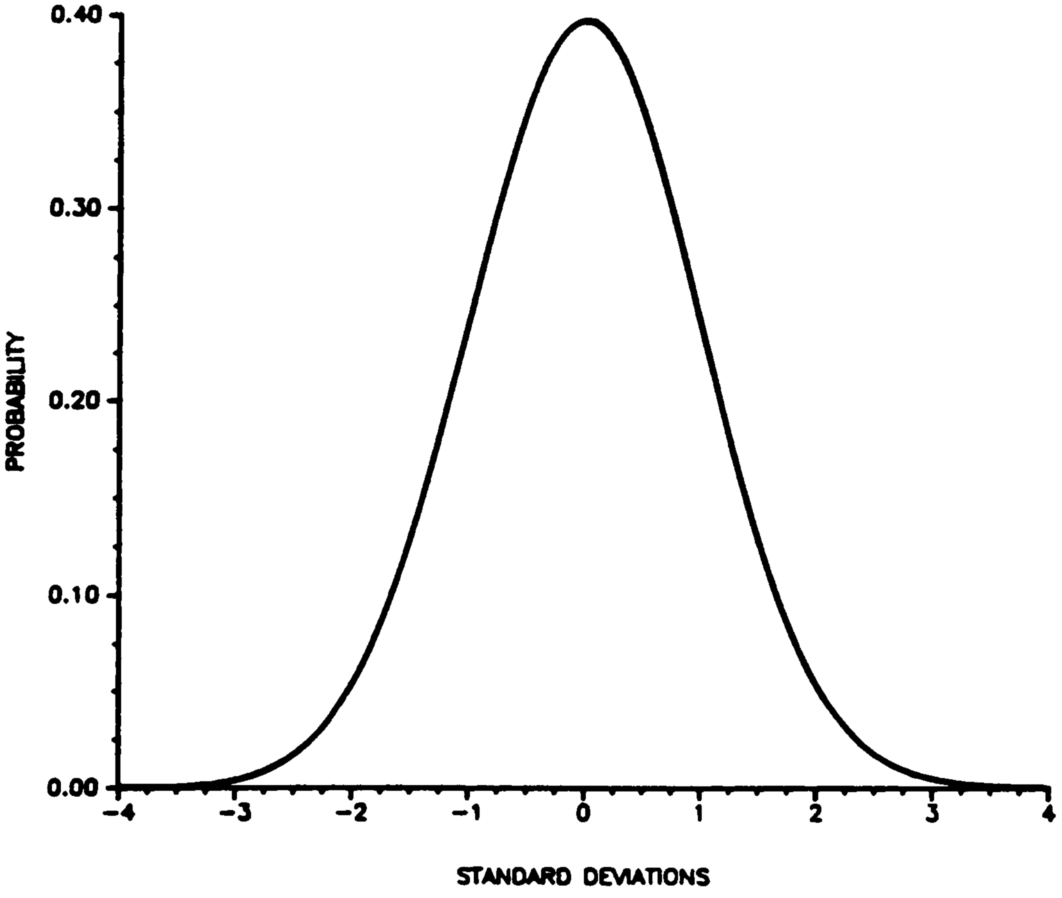

Figure 2. The Standard Normal distribution.

Congleton and Everett (17), and Oltenacu et al. (63) have adapted the Incomplete Gamma function to describe lactation curves in dairy cattle. The equation used by Congleton and Everett (17) to describe the lactation curve was:

$Y_n = A\ n^b e^{-cn}$, where,

Y_n = milk yield (kg) on the n^{th} day in milk

e = base of the natural logarithm

A, b, and c are Gamma parameters that determine Y on day in milk n.

For example, the lactation curve from Congleton and Everett (17) for an average second lactation Holstein cow fresh in December in an average herd with greater than 200 d open would have coefficients A (18.82), b (.23576), and c (.005441). The projected 305 d lactation curve using these coefficients is shown in Figure 3. Cumulative milk yield is estimated by summation of daily yield for the duration of the lactation, which for this example lactation is 7951 kg. Increasing the A coefficient raises the entire curve, thus increasing yield uniformly over the lactation. Multiplying A by a factor of 1.07 increases lactation yield 454 kg. Congleton stated that modification of the b coefficient changed the rate of increase in yield before peak production, and modification of the c coefficient changed the rate of decline after peak production. The day of peak daily milk yield is predicted by $\frac{b}{c}$ and persistency is predicted by $c^{-(b+1)}$. Decreasing b or increasing c, or a combination of both, would decrease persistency of the lactation curve.

Oltenacu et al. (63) also used the Incomplete Gamma function to predict daily milk yield. Included in their equation were factors to account for days pregnant, with increasing days pregnant resulting in lower yield. Congleton and Everett (17) modified the b and c coefficients to account for days pregnant. The equation used by Oltenacu et al. (63) was:

$Y_n = A\ n^b e^{cn} (P+1)^d e^{gP}$, where,

Y_n = daily milk yield (kg) on the n^{th} day in milk

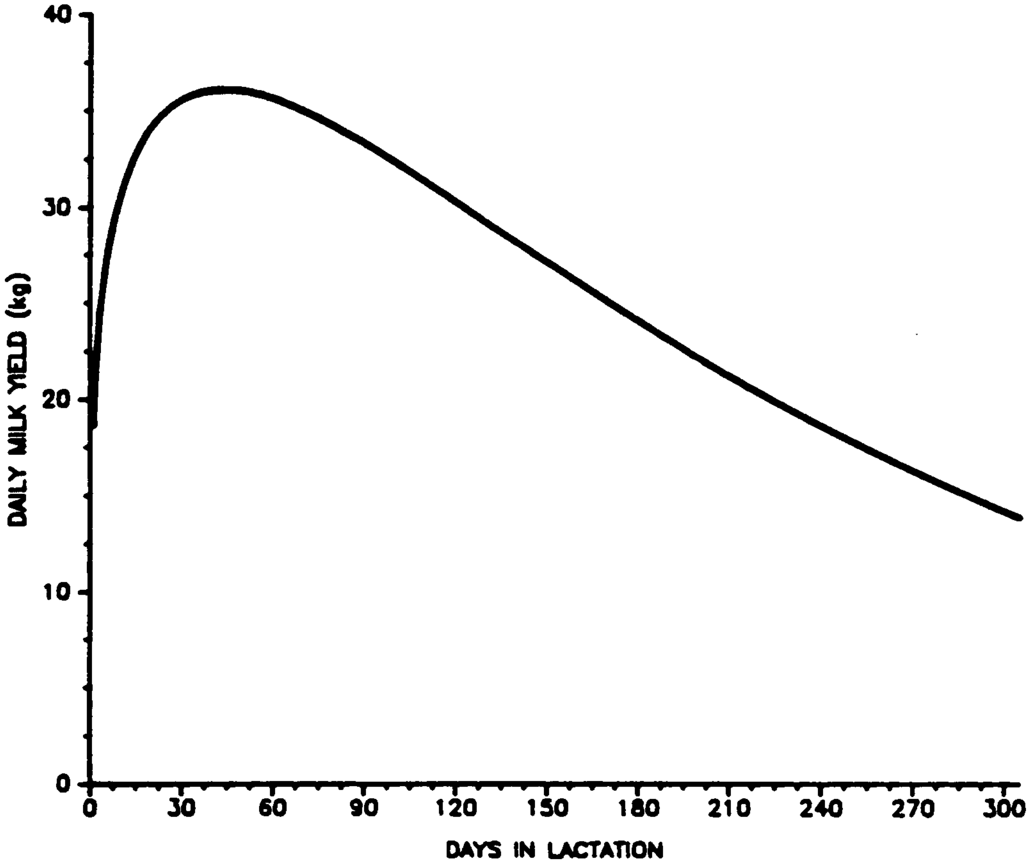

Figure 3. The Incomplete Gamma distribution used to predict daily milk yield from lactation curve data of Congleton and Everett (17).

P = number of days pregnant, beginning with day 90 of pregnancy

e = base of the natural logarithm

A, b, c, d, and g are Gamma parameters that determine Y on day in milk n.

A, b, and c are similar in nature to values used by Congleton although they differ in magnitude, and c differs in sign. Factors d and g were included to account for effects of gestation, which implies an effect of days open because pregnant cows are no longer open. This appears to be a simpler method of including the effects of gestation than modification of the b and c parameters as proposed by Congleton. Figure 4 shows 305 d lactation curves from the Oltenacu equation for second lactation cows with days open of 60, 90, 120, and 305 d. The curve representing 305 d open (i.e., 0 d pregnant) results in the greatest cumulative yield (6203 kg), followed by 120 d open (6106 kg), 90 d open (6029 kg), and 60 d open (5928 kg). It was not mentioned if this prediction was for a herd of average milk yield, so cumulative yield could be different from the Congleton prediction. Coefficients used for prediction of the lactation curves in Figure 4 are A (20.59), b (.12), c (-.004), d (.04), and g (-.002). The A, b, and c coefficients have the same effect on the lactation curve as the values used by Congleton, whereas d has the effect of raising or lowering the curve after pregnancy occurs, and e changes the slope of the curve after pregnancy occurs.

The number of cows in a herd in different age groups or lactations approximates a Negative Exponential distribution. This means that there is a relatively large number of young animals in an average herd, with fewer cows in each successive age group. The number in each group gradually declines and approaches 0 as cows become very old. The equation of the Negative Exponential distribution is:

$Y_i = \frac{1}{\mu} e^{(-i/\mu)}$, where,

Y_i = exponential probability at the i^{th} point

μ = mean of the exponential distribution

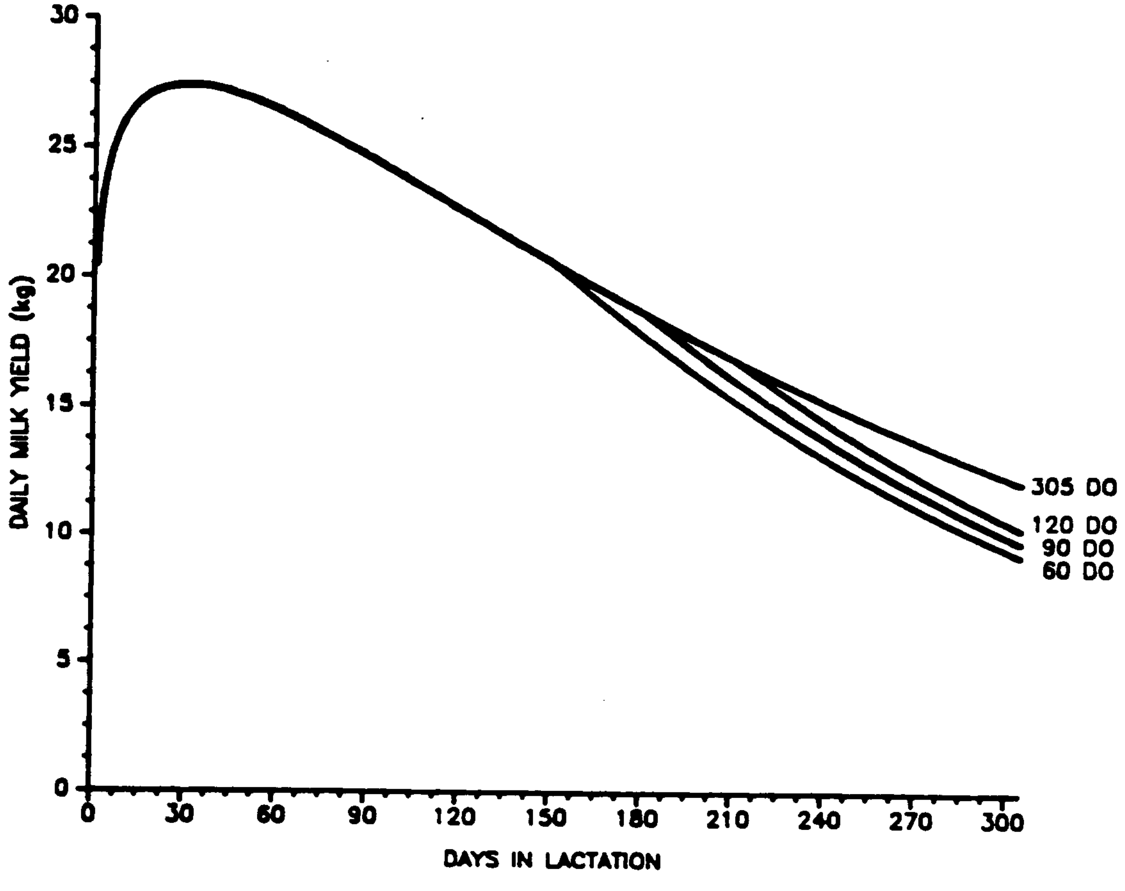

Figure 4. The Incomplete Gamma distribution used to predict daily milk yield, including effects of days open (DO), from lactation curve data of Oltenacu et al. (63).

i = number of the point to generate, i = 1 to n

e = base of the natural logarithm

In many cases it is desirable to create a discrete number of points, for example 10 age groups. Figure 5 illustrates an Exponential distribution of lactations in a herd with a mean lactation number of 3. The probability approaches 0 as the number of lactations becomes large, but does not reach 0 until the number of lactations reaches infinity. Hence, the sum of probabilities of a discrete number of values is less than 1. Therefore, probabilities of occurrence of each value must be adjusted so that the probabilities sum to 1. This can be done by summation of the discrete probabilities, and dividing each individual probability by that sum.

Oltenacu et al. (62) used the Gamma distribution to predict the number of days to first estrus period. The Gamma distribution is used in preference to a Normal distribution when values from the distribution may be skewed. Parameters of the Gamma distribution may be modified to achieve the desired degree of skewness. The probability distribution function, for values of X greater than 0, is:

$$f(X;\alpha B)=\frac{1}{B^{\alpha}\Gamma(\alpha)}X^{\alpha-1}e^{-X/B},$$ where,

$f(X;\alpha B)$ = probability of occurrence of the value X, given parameters α and B

α, B = Gamma parameters, $\alpha > 0$, $B > 0$

$$\Gamma(\alpha)=\int_0^{\infty}X^{\alpha-1}e^{-X}dx$$

X = predicted value

e = base of the natural logarithm

When using this function, values for the α and B parameters can be predicted from the mean and variance of a sample set of data. The α andB are estimated as $E(X) = \mu = \alpha B$ and $Var(X) = \sigma^2 = \alpha B^2$. Solving these two equations for the two unknowns α and B when estimates for μ and σ^2 are known is a simple procedure. For ex-

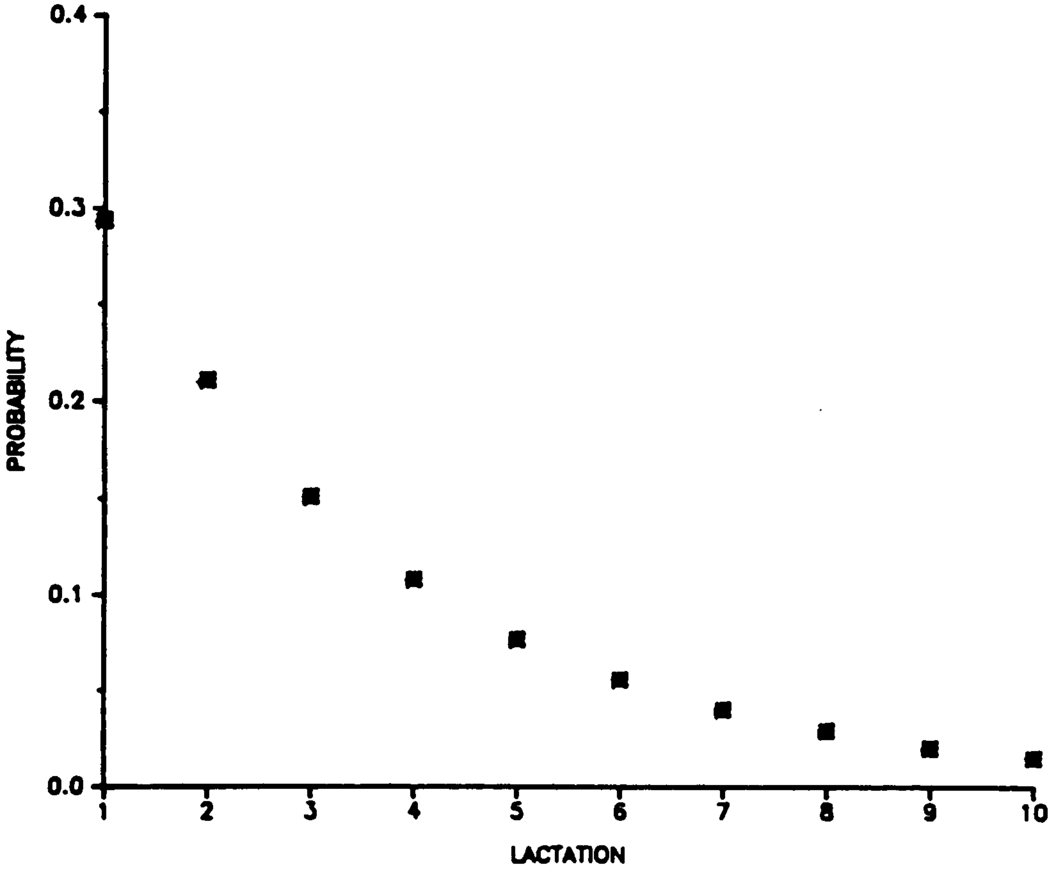

Figure 5. The Negative Exponential distribution.

ample, Oltenacu's estimate of days to first estrus for normal calvings has mean 30 d and SD 25 d; α is 1.44 and B is 20.8. These parameters were then used to estimate probabilities of occurrence for days to first estrus (values of X) from 10 to 80 d. Since the range of 10 to 80 d represents only a portion of the complete Gamma distribution, the probabilities are adjusted so that the sum of probabilities is 1. Similarly for abnormal calvings with mean 50 d and SD 35 d, α is 2.04 and β is 24.5. The value for $\Gamma(\alpha)$ can be assumed to be 1 when $X > 12$ and $\alpha < 3$, and thus is unimportant in these equations.

Figure 6 illustrates the Gamma distribution as used by Oltenacu to simulate days to first estrus in cows with abnormal calvings. It can be seen in Figure 6 that the distribution is skewed to the right when compared with a Normal curve.

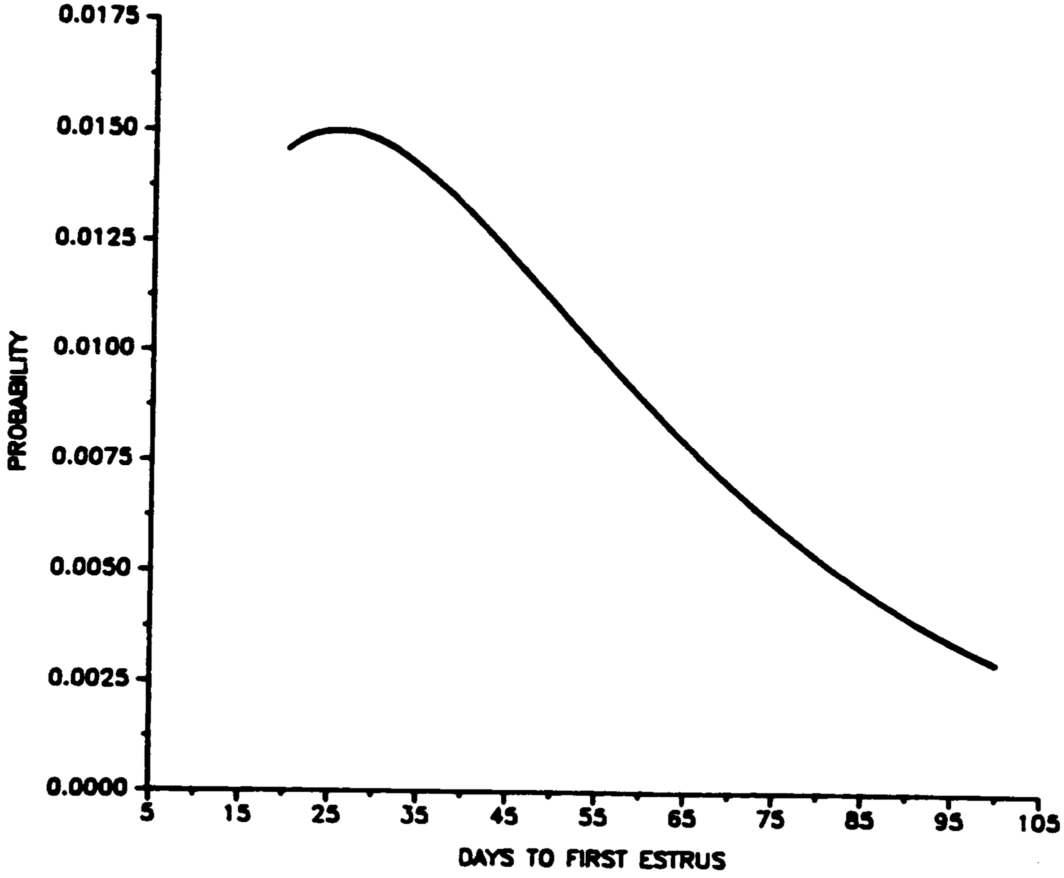

Figure 6. The Gamma distribution, as used by Oltenacu et al. (62) to estimate days to first estrus in cows with abnormal calvings.

Materials and Methods

There are two basic objectives involved in the current research. First is development of a dairy herd simulation that contains many of the relationships considered important in management programs of modern dairy farms. These relationships will be identified as construction of the model is documented. It is desirable that this simulation operate on a microcomputer for future flexibility and distribution. The second objective is to use the simulation to evaluate characteristics of cows and herds in response to variation in model parameters approximating differing types of management. Characteristics considered important are the magnitude and timing of income, expenses, and net return for cattle. In this study net income is expressed on a cash basis as income received from milk, fat, cull cows, bull calves, and pregnant heifers minus fixed expenses, feed expenses, breeding expenses, and health expenses. Fixed expenses include housing, labor, taxes, and insurance, but do not include interest on average investment.

Specific variables measured on cows and herds in these analyses will be described in the objectives. Variables evaluating profit represent measurements on both a cow and herd basis, so separate evaluations will be required for cows and herds. This section of the paper will present the objectives for evaluation of specific management alternatives, the experimental design to test differences among the alternatives, and development of a simulation model that will make this evaluation possible.

Five factors representing levels of management expertise have been selected for evaluation because of their hypothesized importance in management programs. Two of these factors, milk yield of cows and sire merit for PD Dollars, are assumed continuous in nature. The remaining three factors are involuntary culling of cows, rearing of heifers, and sire selection against dystocia in heifers. While the underlying properties of these factors may be continuous, they are treated as discrete in this study so that different levels of each may be compared. Levels of these three factors are high (24%) versus low (12%) involuntary culling, heifer rearing that results in young (26 mo) and old (32 mo) age at first calving, and sire selection against dystocia in heifers (random mating of a group of AI bulls to heifers versus breeding heifers only to bulls rated superior for calving ease). The three factors with discrete levels will be arranged in a 2^3 factorial design (8 treatments) while milk yield and sire merit for PD Dollars will be measured as continuous variables within each treatment combination. A description of each of the five factors follows.

Factors to be Evaluated in Current Study

Involuntary Culling

Total culling in herds in this simulation is 30% of the cows in the herd each year. Two levels of involuntary removal of cows from herds will be evaluated in the study. Low involuntary culling (12%), representative of good management, allows for removal of more animals voluntarily for low net income and pregnancy status. High involuntary culling (24%) represents a restriction in the opportunity to cull animals voluntarily, and thus is poor management. For both levels of involuntary culling, 40% of involuntary culls will be for reproductive reasons, 20% will be for mastitis, 24% will be for disease, and 16% will be for death, which agrees with work of Foster et al. (31). Voluntary culling will be performed on an index of net income for the current lactation, with consideration given to the pregnancy status of the animal.

Heifer Rearing

Levels of heifer rearing are described as target ages at first calving of 26 and 32 mo, with 26 mo age at first calving representing good management. All heifers are raised identically from birth to 6 mo of age. Heifers in the good management system are raised at a faster rate of growth from 6 mo to breeding to achieve earlier breeding, and thus create the difference in age at first calving. The breeding period begins when body weight of the heifer reaches 320 kg. The cost per kg of dry matter intake is the same under both growth rates from 6 mo to breeding, but heifers under the slow growth rate generally eat less and cost less to feed per day. However, heifers under the slow growth rate eat less over a longer period of time; thus they have higher total feed costs and fixed costs than heifers raised under faster growth rates. From breeding to calving the time period is equal (about 280 d) but heifers calving in the 32 mo option will gain at a faster rate and be slightly heavier at first calving (520 vs 490 kg). This assumes heifers that calve at older ages are heavier at first calving. Involuntary culling of heifers from birth to first calving totals 15% in both options due to death and removal for reproductive problems (sterility). Voluntary culling is performed on pregnant heifers so that only enough heifers freshen to maintain the 30% total culling rate in the milking cow herd.

Dystocia due to Sires

The two levels of dystocia are to be compared. One option for dystocia is random mating of bulls available each year to heifers regardless of bull dystocia rating. The other option is to breed heifers with bulls that have a lower probability of difficult births. Cows will be mated randomly to all bulls available each year in both options. Bulls created in the simulation are assigned values that represent the expected percent difficult births in heifers. These values are correlated to the bulls' breeding values for stature, implying bulls that sire tall cows sire larger calves at birth, which results in more dystocia problems. In this study, calving ease bulls have values for percent difficult births that are less than 1 SD below the expected mean (9%) for percent difficult births of all bulls. Therefore, calving ease bulls have values of less than 7% for expected percent difficult births in heifers.

Each year of bulls in the study is required to have at least 2 calving ease bulls, but can have more than 2 bulls meeting those requirements. When selection against dystocia is practiced, all matings to heifers are made with calving ease bulls. This will create a slightly heavier usage of these bulls in the selection option (compared to random mating) due to their random use on milking cows as well as exclusive use on heifers. The effect of dystocia is manifested to a large degree in the size of the calf born. As such, birth weights of calves from dystocia births are heavier, and these animals will have a slightly faster growth rate. In this study dystocia is considered a trait of the sire only, in that cow effects for dystocia are not included in the model.

Milk Yield

Milk and milk fat yield are the main components of income in this study, and their effect on profit will be of interest. Milk yield is a continuous variable, estimated as the permanent herd effect for milk yield in the herd study, and by the sum of the breeding value, permanent herd effect, and permanent cow effect for the cow study. One objective is to measure the magnitude of those differences. Increases in production normally represent increases in net income through improved efficiency of production. Therefore, differing levels of production should have an effect on the income and expense structure of the farm. Cows and heifers are fed according to requirements specified by the National Research Council (55), with variations included in daily dry matter intake to estimate variability in intake, and thus growth and milk production. High production per cow is an indication of good herd management practices.

Sire PD Dollars

The magnitude of differences in income and expense of cows due to differences in merit of their sires for PD Dollars is also of interest and will be measured. PD Dollars is not a factor in the herd study, because all herds use the same bulls in approximately the same proportions each year. In the cow study, PD Dollars affects income of daughters of the bulls inasmuch as PD Dollars represents milk and fat production transmitted to the offspring. Genetic potential for production is the only factor related to performance in cattle that is permanently transmitted across generations. Genetic progress is brought about through the selection of parents, with sire selection most important because of its high intensity. One-hundred twenty bulls are created for each year of the simulation, and the best 20 bulls (1 out of 6, based on their value for PD Dollars) are retained for use in matings. The 120 bulls represent a population of all bulls, and the selected bulls represent an AI population. This provides bulls for use with evaluations for PD Milk, PD Dollars, and other traits that are representative of bulls in the AI population during the past 10 yr. All bulls have different breeding values for milk and fat, and thus different PD's for milk, fat, and dollars. Production, and therefore the income and expense structure of daughters of bulls will differ between bulls.

Experimental Design

The experimental design for this study involves a comparison of combinations of the 5 factors listed above for cows and herds simulated for 20 yr. Eight model runs will be required to evaluate all options of the 2^3 factorial combination of involuntary culling, heifer rearing, and selection against dystocia in heifers. Because characteristics of individual cows and herds are measured differently, evaluations will be performed separately for each of them. The simulation of herds assumes herds are run under circumstances of normal management, meaning voluntary culling will be practiced that approximates normal culling procedures, and cows that survive will offset expenses of cows that were removed from the herds. The evaluation from the cow simulation, rather than the herd simulation, will be used to determine net income characteristics of cows over their lifetime. Thus, no voluntary culling will be performed, giving all cows the opportunity to express complete herdlife. Cows will offset their own expenses in this part of the study, but not the expenses of other cows in the herd.

For the evaluation of herd characteristics 20 herds, each with 80 cows plus youngstock, will be simulated for 20 yr under each of the 8 options. Each option will begin with the same initial set of 20 herds. Data from cows created for the initial 20 herds will not be included in the analyses because there is no way to collect accurate income and expense information on these cows prior to the start of the simulation. All calves born after the initial year will be used in the analyses.

For evaluation of characteristics of cows, data will be generated such that at least 1000 cows will have a first freshening in each option. More than 1000 animals must be born because involuntary culling is applied to heifers. The 1000 animals studied will be progeny of animals created in an initial herd so that information on the animals can be collected from birth. Dams of the animals evaluated will be eliminated from the analyses. Herds will not be a factor in this analysis since all animals will essentially be from one herd. Income will be credited to the cows for milk and fat production, salvage value when removed, and salvage value of all progeny born alive (heifers and bulls). The same set of initial cows will be used to create animals for each of the 8 options. The simulation will continue for each option until all animals have completed their herdlife to a maximum of 10 lactations. This implies that future milk income from progeny is not credited to the animal in question.

Components of income for cows in the herd study will be income from milk and fat production, salvage value for culled cows, and value for bull calves sold. For the cow study, income is included for heifer calves also, as all calves will be sold with the income credited to cows. Before first freshening, heifers cannot be credited with income unless they are sold as non-breeders or excess pregnant heifers.

Components of expense in both studies are allocated separately for calves and cows. All animals are charged fixed, feed, and other expenses. Daily fixed expenses for heifers ($.40/d) do not change from birth to first calving, and include charges for facilities, taxes and insurance, bedding, labor, vaccinations, and routine health exams. Feed expenses include all feeds consumed from birth to first calving. Feed expenses vary during this period as the quality, quantity, and cost of feeds required vary during the rearing period. Other expenses for heifers include breeding fees, expenses for heat detection, and pregnancy determination.

Daily fixed expenses for cows are different for first, second, and later lactations ($1.05, $1.18, and $1.26/d), reflecting differences in labor requirements. These include charges for facilities, taxes and insurance, bedding, labor, and vaccinations. They do not include fixed expenses for heifers as in some studies. Feed expenses for lactating cows are calculated from intake of energy and protein. Since higher quality energy and protein are required in larger amounts for maintainence of high production, expenses per unit of energy and protein increase as their concentration increases in the cow's diet. Other expenses for cows are for breeding, heat detection, health, and pregnancy determination. Income and expenses, feed intake, milk yield, and weight loss/gain are calculated on a daily basis. To increase computational speed daily values are multiplied by 10 for cows (cows are moved through time in 10 d increments) and 14 for heifers. Income and expenses are accumulated and stored on a monthly basis for statistical analyses.

Objectives of the Herd Study

The main objective is to determine the effect of the three factors and two covariates involved in this study on time to payoff of expenses and profit by measuring differences in herd response as levels of the factors change. Specific response variables are described in the sub-objectives listed below.

1. The objective is to determine the effects of two levels of involuntary culling, heifer rearing, and sire dystocia (8 total options) on the length of time to cumulative payoff of expenses. Time to cumulative payoff is calculated by accumulating monthly income and expenses for all heifers born in each separate herd-year of the study. This value includes income and expenses for calves that die after birth, are sold as non-breeders, are sold as pregnant heifers, that enter the milking herd but do not return a profit, and that eventually become profitable. Cows that make profit are charged their own rearing expenses plus the cost of production after first calving, plus they must offset, on a herd basis, the accumulated expenses of other heifers that did not make a profit. Heifers that are sold before their first calving as non-breeders receive

a salvage value equal to their market price. Pregnant heifers sold receive a salvage value equal to their accumulated expenses up to the time of their removal.

For each herd-year, a single value will be calculated representing the months to cumulative payoff for all calves born in that herd-year. It is possible that some herd-years will not attain a cumulative payoff, especially in later years of the data. Herd-years without a month to cumulative payoff will be deleted from the analysis. The model used for evaluating the time to cumulative payoff is:

$$Y_{ijklm} = \mu + B_i + C_j + R_k + D_l + (CR)_{jk} + (CD)_{jl} + (RD)_{kl} + (CRD)_{jkl} \\ + H(CRD)_{jklm} + (BC)_{ij} + (BR)_{ik} + (BD)_{il} + e_{ijklm} \quad [1]$$

where

Y_{ijklm} = time to cumulative payoff, in months, for all heifers born in the i^{th} year, with the j^{th} level of involuntary culling, k^{th} level of heifer rearing, l^{th} level of selection against dystocia, and in the m^{th} herd

μ = overall mean

B_i = effect of the i^{th} year of birth, i = 76 to 94

C_j = effect of the j^{th} level of involuntary culling, j = 1,2

R_k = effect of the k^{th} level of heifer rearing, k = 1,2

D_l = effect of the l^{th} level of selection against dystocia in heifers, l = 1,2

$(CR)_{jk}$ = interaction of involuntary culling with heifer rearing

$(CD)_{jl}$ = interaction of involuntary culling with selection against dystocia

$(RD)_{kl}$ = interaction of heifer rearing with selection against dystocia

$(CRD)_{jkl}$ = interaction among involuntary culling, heifer rearing, and selection against dystocia

$H(CRD)_{jklm}$ = effect of the m^{th} herd within the three way interaction

$(BC)_{ij}$ = interaction of birth year of heifers with level of involuntary culling

$(BR)_{ik}$ = interaction of birth year of heifers with level of heifer rearing

$(BD)_{il}$ = interaction of birth year of heifers with level of selection against dystocia

e_{ijklm} = random residual.

All effects in model [1] except herds and e_{ijklm} are fixed. Herd within the three way combination of involuntary culling, age at first calving, and sire dystocia will be used to test main effects and interactions among the factors. An alternative model to be evaluated will substitute the permanent herd effect for milk yield as a covariate for herds, with the herd within three way interaction removed from the model. Thus, main effects will be tested by the residual error term in this model. Partial regression coefficients will be estimated for main effect by herd interactions in this case. PD Dollar values for sires are not included in either of these models, as all herds use the same sires each year. Therefore, differences between herds based on sire merit for PD Dollars should not exist.

2. The objective is to determine the effects of two levels of involuntary culling, heifer rearing, and sire dystocia on profit per animal day to a fixed age of 96 mo. The purpose is to quantify differences among options with a monetary value. One value for profit per animal day at 96 mo will be calculated within each herd-birth year, similar to the time to cumulative payoff of objective 1. Profit per animal day will be calculated as total income minus total expense for all animals born in each herd-birth year combination, divided by the total days of herdlife of these animals, accumulated through 96 mo of age (8 years). Income and expenses received after 96 mo of age will not be included in this value, nor will days of herdlife beyond 96 mo be included. Two estimates of profit per animal day will be evaluated. The first estimate will include salvage value as income for any animals still alive at 96 mo. The second estimate will not include a salvage value for these animals. Comparison of the two will indicate systems profiting more from cow longevity than from net cash income, because of the benefit given to options with more live cows at 96 mo.

The two models used for the evaluation of objective 2 will be the same as for objective 1, substituting the dependent variable profit per animal day for time to cumulative payoff. Analyses will be separate for the two estimates of profit per animal day, emphasizing the most desirable model from objective 1.

3. The objective is to determine the effects of two levels of involuntary culling, heifer rearing, and sire dystocia on net cash income and milk yield. Net cash income and milk yield will be measured per cow per year. The purpose is to determine if the eight options studied, net cash income, and milk yield are similar measures of herd performance. As the simulation progresses, milk yield, income, and expenses are accumulated monthly for all cows in all herds, including dry cows but not including heifers. Accumulating income and expenses within herd for an entire year, and dividing by the average number of cows in the herd for the year, will estimate net cash income/cow/herd/year. In this objective year represents the year of production and not birth year of the animal. Milk yield/cow/herd/year will be calculated similarly. One value for net cash income and milk yield will be calculated for each herd-year of the simulation. Milk yield and net cash income of cows in the initial herds are included in these estimates as long as those cows remain in the herds. This differs from previous analyses because these variables will be accumulated monthly starting in the second year of the simulation, and previous history of these cows will not be important.

   The two models used for the evaluation of the eight options on net cash income and milk yield will differ from the models of objective 1 in that the independent variable year in these models represents the year of production and not birth-year.

4. The objective is to determine the effect of two levels of involuntary culling, heifer rearing, and sire dystocia on herd measurements representing DHIA variables. Herd measurements are averages calculated within herd and year of the simulation for age at first calving, days open, days dry, number of services per conception, days to first heat, and days to first breeding. Dependent variables days open and number of services per conception are calculated for all pregnant animals, based on records completed in the given year. Average age at first calving is calculated from all heifers that calved during the year. Days dry is calculated from all records completed in the year where a cow had a complete dry period following her lactation. Days to first heat is calculated on all cows in a year with completed records (including records completed with a cull code), and days to first breeding is calculated on all cows bred, whether or not they became pregnant. One value for each of these variables is calculated within herd and year, with the independent variable year representing years of the simulation. The purpose is to evaluate whether these dependent variables are influenced by the eight options. In some instances these variables are directly influenced by the options, such as age at first calving. Other variables are not directly affected by the options, but may still be related to them. Models used to evaluate objective 4 will be the same as those used for evaluation of objective 3.

Objectives of the Cow Study

Response variables for the cow study are different from the response variables used for the herd study because no voluntary culling is applied in the cow study, allowing cows opportunity for "complete" herdlife. Concentration is on profit from the individual, independent of other animals in the herd. Specific response variables of interest are listed in the sub-objectives below. Herds are not a factor in the cow study since all cows are assumed to be from a single large herd, and birth year of heifers will not be a factor either because all cows evaluated are born in a single year. Years of the simulation will be a factor in the study inasmuch as temporary herd and cow effects for production are assigned yearly, thus influencing production of cows appearing in those years.

1. The objective is to determine the effects of two levels of involuntary culling, heifer rearing, and sire dystocia, plus effects of cow merit for production and sire merit for PD Dollars, on time to cumulative payoff of individual cows. Cow merit is estimated as the sum of the cow's breeding value, permanent herd, and permanent cow effects for milk yield, which includes the sire's PD Dollars as well as other environmental factors. Sire merit for PD Dollars is estimated for a cow as her sire's PD Dollars. The PD Dollars of the cow's maternal grandsire is included in her cow merit through her dam, but maternal grandsires are not included in the statistical model because many cows in the initial year did not have identified maternal grandsires. Time to cumulative payoff is the age of the animal in months when accumulated income equals accumulated expenses. Accumulated expenses include the cost of rearing plus the cost of production after first calving. Because individual cows are not profitable during their dry period, a second measure of time to payoff of expenses will also be measured. This measure, time to cumulative profit, represents the age of the cow where her accumulated income equals or exceeds her accumulated expenses for the subsequent 12 months. This will be a measure of long term profitability of cows. Accumulated income for animals in the cow study includes milk and fat yield, and a salvage value for heifer and bull calves born alive. Cows are credited with their own salvage value when they are involuntarily culled for reasons other than death.

The model used to evaluate time to cumulative payoff and time to cumulative profit is:

$$Y_{ijklm} = \mu + C_i + R_j + D_k + (CR)_{ij} + (CD)_{ik} + (RD)_{jk} + (CRD)_{ijk} + b_1 P_l + e_{ijklm} \qquad [2]$$

where

$Y_{ijkl} =$ time to cumulative payoff or profit for the l^{th} cow, with the i^{th} level of involuntary culling, j^{th} level of heifer rearing, and k^{th} level of sire selection against dystocia in heifers

$\mu =$ overall mean

$C_i =$ effect of the i^{th} level of involuntary culling, $i = 1,2$

$R_j =$ effect of the j^{th} level of heifer rearing, $j = 1,2$

$D_k =$ effect of the k^{th} level of sire selection against dystocia in heifers, $k = 1,2$

$(CR)_{ij} =$ interaction of involuntary culling with heifer rearing

$(CD)_{ik} =$ interaction of involuntary culling with selection against dystocia

$(RD)_{jk} =$ interaction of heifer rearing with selection against dystocia

$(CRD)_{ijk} =$ interaction among involuntary culling, heifer rearing, and sire selection against dystocia

$P_l =$ cow merit of the l^{th} cow, in kg

$b_1 =$ linear regression coefficient for production

$e_{ijkl} =$ random residual.

All effects in model [2], except e_{ijklm}, are fixed. Model [2] will be evaluated for different groups of animals to determine if relationships between dependent and independent variables differ by group. Groups will consist of all cows having a time to cumulative payoff, all cows having a time to cumulative profit, and all cows that survived to 96 mo. Alternative models evaluating time to cumulative payoff and profit will be analyzed with effects of cow merit removed from the models, as well as substituting sire PD Dollars for cow merit to help determine the importance of PD Dollars and the main effects in the absence of cow merit.

2. The objective is to determine the effects of two levels of involuntary culling, heifer rearing, and sire dystocia, plus effects of cow merit for production and sire merit for PD Dollars on net income per day for individual cows. Two estimates of net income per day will be evaluated. First is net income per day of herdlife, and second is net income per day through 96 mo of age. Herdlife is the number of days from birth to removal from the herd. Since all animals in this study have complete herdlives, net income per day of herdlife is total income, including salvage value, minus total expenses divided by the number of days of herdlife from birth for individual cows. Net income per day of herdlife through 96 mo will be calculated only for those cows that survive through 96 mo. For the calculation of net income through 96 mo, alternative values will be estimated that include salvage value on the cows and do not include a salvage value. Models evaluating the effects specified in objective 2 will be the same as for objective 1.

3. The objective is to map cumulative net income per day of life at specified events in a cow's lifetime. Events of interest for youngstock are net income per day at weaning, pregnancy, and first calving. For cows, events for each lactation are cumulative net income per day at calving, 70 d in milk, 140 d in milk, 210 d in milk, time of drying off, and next calving. The purpose is to identify when cows become profitable in terms of completed lactations, rather than in months of age. Because of the large number of combinations of the 2^3 factors times the number of events, raw means for cumulative net income per day at each event will be compared across options to determine if involuntary culling, heifer rearing, and sire dystocia have an

effect on cumulative net income per day. Models containing the 2^3 factors and events, with and without covariates of cow merit for production and sire merit for PD Dollars, will be used to identify significant effects.

4. The objective is to determine the effects of number of mastitis cases, days dry, days open, and number of services per conception on lifetime net income per day of herdlife. Independent variables will be expressed per lactation. Because all animals have complete herdlives, these variables can be calculated on all animals that have completed at least one lactation, and evaluated by regression analyses.

Development of Simulation Models

To generate data that satisfy requirements of objectives of the herd study, three simulation programs must be developed. These programs are written in the Turbo Pascal programming language (10). The first program creates bulls that are representative of the current AI population. The second program generates cows in the initial herds at a specific point in time (the end of the first simulated year). Creation of the initial herds requires that cows in these herds have an age structure representative of herds in general, and that cows be in all stages of lactation and reproductive status. Cows in the initial herd have no record of parentage, although youngstock created in the initial herds from these cows have sires selected from the first year of the bull simulation. The two calf crops in the initial herd are from the same group of sires. The third program simulates the movement of cows and herds through time.

For the cow study, the bull simulation remains the same, and only slight modifications to the other simulations are required. Modifications are needed because there is only one herd in the study, value of heifer calves must be attributed to their dams, no voluntary culling is practiced, and slightly different information is collected. Discussion of model development will not involve presentation of the actual programming code, but will discuss relationships included in segments of the model as they are incorporated into the simulation.

Random Number Generation

A common principle in all simulation programs is generation of random number streams, which are used to determine probabilistic occurrences and create variability in biological measurements on animals. Since random number generation is common to all of the programs in this study and the same random number generator is used in all of the programs, the random number generator will be discussed separately from the simulation programs.

Accurate and reliable random number generation is essential for proper execution of simulation programs. However, microcomputer random number generators provided by software companies are generally not reliable. Problems are encountered with random number streams that have short periods (the sequence of random numbers repeats relatively quickly) or generate numbers that do not pass rigorous tests for randomness. A desirable feature of random number generators not available in many computer software products is the capability to set random number seed values, so that results of a simulation can be duplicated by creating identical streams of random numbers on different machines at different times. The Turbo Pascal random number generator has many of these problems. In particular, seed values cannot be set by the operator of the program.

To alleviate problems with random number generation, procedures for generating random numbers were incorporated into this simulation from several sources. The

Uniform random number generator was incorporated from Wichmann and Hill (92), and is an essential model component as it is the basis for all random numbers used in the simulation. This Uniform random number generator consists of three independent parts (numbers) that are combined to develop a single Uniformly distributed number. This procedure allows for very long random number streams. They stated the period length of their generator, i.e., the number of random numbers created before the sequence repeats itself, is in the range of 6.95 x 10^{12}.

The Uniform random number generator is important for two reasons. First is the generation of numbers to be used directly in estimation of probabilistic occurrences. Second is the creation of numbers representing values from the Standard Normal distribution. To verify the generator, 2000 Uniform random numbers were generated for testing. Frequencies of Uniform numbers appearing in 10 equally spaced classes from 0 to 1 are presented in Table 3. These data were not tested statistically for uniformity, although it appears that the numbers generated are in fact Uniform.

The other important use of Uniform numbers is in the creation of values representing sampling from other distributions. Uniform random numbers are used in this simulation to create values from a Standard Normal distribution, and values from four Standard Normal distributions that are correlated with each other. These distributions are necessary to create values representing biological measurements that are Normally distributed, such as body weight at first calving, and sets of measurements that are multiply correlated and Normally distributed, like breeding values for milk yield, fat percent, and protein percent. Routines to calculate Normal and correlated Normal deviates have been adapted from the simulaton of McGilliard and Edlund (51). Their routines calculated Standard Normal deviates and four correlated Standard Normal deviates from combinations of Uniform random numbers and correlation matrices. An additional adaptation was made in this simulation so that after four correlated deviates

Table 3. Expected and simulated frequencies observed for 2000 Uniform random deviates.

	Frequency		
Probability	Expected	Simulated[1]	Percent
>0.0, ≤.1	200	202	10.1
>.1, ≤.2	200	190	9.5
>.2, ≤.3	200	205	10.3
>.3, ≤.4	200	176	8.8
>.4, ≤.5	200	221	11.0
>.5, ≤.6	200	191	9.5
>.6, ≤.7	200	199	9.9
>.7, ≤.8	200	242	12.1
>.8, ≤.9	200	176	8.8
>.9, ≤1.0	200	198	9.9

[1] For these 2000 simulated Uniform numbers, the mean was .50, the SD was .2872, and the variance was .0825. Expected mean is .5, and expected variance is .0833.

were calculated, the first deviate could be retained so three more correlated deviates could be generated. This allowed for the creation of two sets of deviates, with random numbers in each set multiply correlated to each other, and the first random number in each set equal. These two sets of random deviates are used to incorporate correlation matrices of milk yield with fat percent, protein percent, and somatic cell count; and of milk yield with linear type scores for stature, dairyness, and udder depth.

Figure 7 shows the distribution of 2000 Standard Normal deviates created to test the random number generator for Normal values. Although statistical testing for normality was not done, the numbers appear normally distributed. Testing of correlated Standard Normal deviates was done by creating 2000 correlated deviates from the generator. Table 4 presents expected and observed correlations between the 4 correlated deviates. Just as Standard Normal deviates can be adjusted to represent any normal distribution, correlated Normal deviates can be adjusted to any expected correlation matrix by supplying the desired correlations to the program.

Bull Simulation

Because this simulation attempts to mimic real-life occurrences of current dairy conditions, it is important for components of the simulation to be reflective of the current status of the dairy industry. With respect to bulls, three requirements must be met. First, individual traits on bulls must be simulated that are representative of important traits currently used in the AI industry. Second, biological values for these simulated traits should approximate means, variability, and correlations found in the current population. Finally, bulls that are used for matings should be a selected subset of bulls from a general population, thus representing current industry practices. Since this simulation spans 20 yr of time, point estimates of mean values cannot be used. Because of genetic

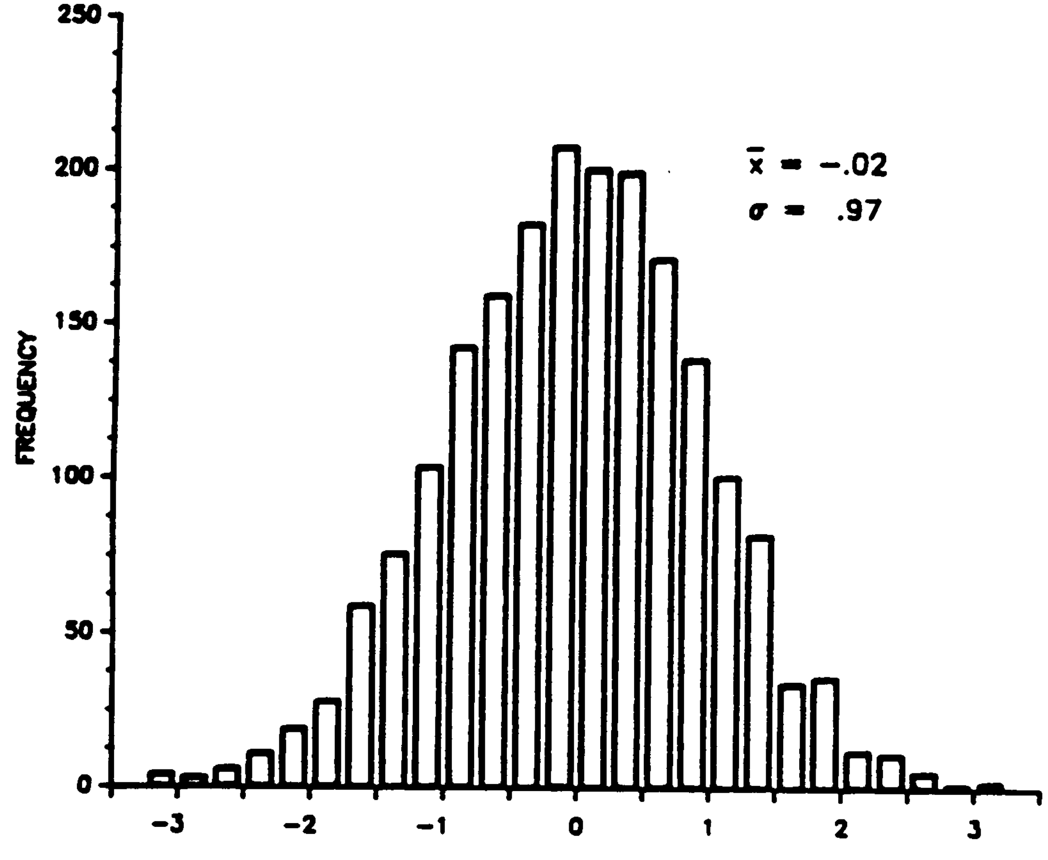

Figure 7. Frequencies of 26 classes of Standard Normal deviates, estimated from 2000 simulated random numbers.

Table 4. Expected (above diagonal) and observed (below diagonal) correlations for 2000 simulated pairs of four correlated Standard Normal deviates.

Random number[1]	1	2	3	4
1	--	-.14	-.18	.10
2	-.13	--	.40	.15
3	-.19	.43	--	.15
4	.09	.14	.17	--

[1] Means and SD for the 4 Normal deviates were as follows: Means = (-.02, -.03, .00, -.01), SD = (.98, 1.0, .98, .97).

time trends for production, bulls in the later years of the simulation should be superior to bulls appearing in the earlier years. Therefore, genetic values for milk yield for the initial bulls should be lower than current averages, so that bulls used over the 20 yr period will have averages close to values currently reported.

Population parameters (unknown means) for all transmitted traits ($n = 7$) in the base year of simulation will be zero. Transmitted traits are traits with breeding values assigned in this simulation, with the breeding value transmitted to the next generation. Non-transmitted traits are either estimated from the transmitted traits, as in PD Dollars, or are estimated without assigning breeding values in this simulation, as in expected percent difficult births. This does not mean the non-transmitted traits are not genetic, just that they are not used that way in this simulation. As the simulation is genetically based, all bulls in the unselected population will have breeding values calculated on them for the following transmitted traits: Milk yield, fat percent, protein percent, and SCC; and linear type traits stature, dairyness, and udder depth. Milk yield and fat percent are included because they represent the marketed product. Protein percent is included because it is a trait of continually increasing popularity and because of its inclusion in milk pricing systems in many sections of the US. Percentage of fat and protein are included rather than their yield, although yield of fat and protein can be calculated from milk yield and the percentages. Percentages were included in the simulation because reliable estimates of permanent and temporary herd and cow effects were available on them, and because parameter estimates were available for the relationship of percent fat and protein with SCC. The SCC was included in the simulation although it is not currently used. Future plans are to use SCC in predicting clinical and subclinical mastitis, milk loss due to mastitis, and milk quality.

The traits milk yield, fat percent, protein percent, and SCC are important individually, but also as a group because genetic, phenotypic, and environmental correlations exist among these traits. Correlations among the traits result in the relationships observed among the traits at the farm level. Table 5 lists the genetic, phenotypic, and environmental correlations, plus heritabilities used for these four traits. Genetic and phenotypic correlations among milk, fat percent, and protein percent are from a summary by Maijala and Hanna (47). Genetic and phenotypic correlations of milk yield, fat percent, and protein percent with SCC are from Monardes et al. (53). Heritabilities for milk yield, fat percent, and protein percent are from Van Vleck (89), and for SCC are from Monardes et al. (53). Environmental correlations for each pair of traits are calculated directly from genetic correlations, phenotypic correlations, and heritabilities of the traits using the following equation:

$$r_{e(1,2)} = \frac{r_{p(1,2)} - r_{g(1,2)}\sqrt{h_1^2 h_2^2}}{\sqrt{(1 - h_1^2)(1 - h_2^2)}}$$

where

$r_{e(1,2)}$ = environmental correlation between traits 1 and 2

$r_{p(1,2)}$ = phenotypic correlation between traits 1 and 2

$r_{g(1,2)}$ = genetic correlation between traits 1 and 2

h_1^2 = heritability of trait 1

h_2^2 = heritability of trait 2

In this simulation linear type trait evaluations for bulls, and scores for linear type traits on cows are simulated rather than PD Type and final score, which was done by other researchers (51, 93). The simulation of linear type traits is possible because parameter estimates are now available of the relationships among linear type traits, and of linear type traits with milk yield. Estimates of genetic and phenotypic correlations among milk yield, stature, dairyness, and udder depth, plus heritabilities of the linear traits are from Foster et al. (30). Dairyness and udder depth are included because of the

Table 5. Genetic, phenotypic, and environmental correlations, plus heritabilities used in the simulation of milk yield, fat percent, protein percent, and SCC.

Trait pair	Correlations				
	Genetic	Phenotypic	Environmental[1]	Heritability[2]	Source[3]
Milk/Milk	1.00	1.00	1.00	.25	(47,89)
Milk/Fat%	-.31	-.21	-.16		(47,89)
Milk/Protein%	-.28	-.26	-.27		(47,89)
Milk/SCC	.48	-.08	-.18		(53)
Fat%/Fat%	1.00	1.00	1.00	.60	(47,89)
Fat%/Protein%	.58	.49	.39		(47,89)
Fat%/SCC	-.05	.00	.02		(53)
Protein%/Protein%	1.00	1.00	1.00	.50	(47,89)
Protein%/SCC	-.07	.06	.11		(53)
SCC/SCC	1.00	1.00	1.00	.09	(53)

[1] Environmental correlations are calculated directly from heritability, genetic, and phenotypic correlations.

[2] Heritability reported is for the first trait of the pair, listed once only.

[3] Source of estimate from literature.

large magnitude of the relationship between them and milk yield (30), and because of their importance in predicting final score of cows and PD Type of bulls. Stature is included in the model because of the relationship of stature to PD Type, but also because of the relationship of stature to body size (39). Stature will be incorporated into the model as a component of the trait percent difficult births in heifers. PD Type is not important in this simulation except in the use of PD Type to help predict semen price. PD Type is not simulated directly, but is predicted from the linear type evaluations of dairyness, udder depth, and stature. This appears a desirable way to estimate PD Type, as reasonable estimates are available for the relationship of the linear type traits with production, and for linear traits with PD Type.

Genetic, phenotypic, and environmental correlations, plus estimates of heritability among milk yield, stature, dairyness, and udder depth are in Table 6. Milk yield is correlated to fat percent, protein percent, and SCC (Table 5), and milk yield is correlated to stature, dairyness, and udder depth (Table 6). This implies correlations also exist between fat percent, protein percent, SCC, and the linear type traits, although they are considered not important and will not be used in the model.

In the base year of simulation, breeding values for all traits on all bulls have mean zero. Estimates of biological values are created from distributions by generating a set of correlated Standard Normal deviates, and for each trait multiplying the corresponding deviate by the genetic SD for the trait, and adding that value to the mean for the trait (zero in the base year). Literature estimates of genetic SD for the transmitted traits used in this simulation are in Table 7. Creation of breeding values includes genetic correlations among the traits, so that any trends in traits other than milk yield are due to the correlated response to selection for milk. In successive years after the first, the mean breeding value for milk yield increases 60 kg/yr to reflect genetic trend in the population. Trait means for the bulls actually used are not zero because of the effects of genetic

Table 6. Genetic, phenotypic, and environmental correlations, plus heritabilities used in the simulation of milk yield, dairyness, stature, and udder depth.

Trait pair	Correlations				
	Genetic	Phenotypic	Environmental[1]	Heritability[2]	Source[3]
Milk/Milk	1.00	1.00	1.00	.25	(47,89)
Milk/Dairyness	.56	.30	.15		(30)
Milk/Stature	.11	.07	.05		(30)
Milk/Udder depth	-.12	-.22	-.24		(30)
Dairyness/Dairyness	1.00	1.00	1.00	.25	(30)
Dairyness/Stature	.27	.19	.09		(30)
Dairyness/Udder depth	-.09	-.11	-.15		(30)
Stature/Stature	1.00	1.00	1.00	.36	(30)
Stature/Udder depth	.37	.16	.12		(30)
Udder depth/Udder depth	1.00	1.00	1.00	.24	(30)

[1] Environmental correlations are calculated from heritability, genetic, and phenotypic correlations.

[2] Heritability reported is for the first trait of the pair, listed once only.

[3] Source of estimate from literature.

trend, and also because the bulls used for matings have been selected based on a production index. Inbreeding among animals is not a problem in this simulation because a new set of bulls is created in each year of the simulation, and bulls are not used for matings in more than one year. Also, bulls within a year are assumed unrelated, and are unrelated to bulls used in previous years.

Creation of breeding values for traits on animals is the basis of this simulation. However, in real-life situations breeding values are unknown quantities, and selection of animals must be based on an estimate of their breeding value. In the bull population these estimates are known as Predicted Differences (PD), which actually estimate transmitting abilities (one-half of the breeding value). A measure of confidence in the estimation of PD's is the repeatability of a bull for a given trait. Repeatability is a function of the amount of information collected on a bull, and in theory a repeatability of 1 implies perfect knowledge of a bull's breeding value through his PD. The simulation must work this concept in reverse. Given that a bull's breeding value for a trait is known a procedure was derived to obtain an estimate of his PD. This estimate is obtained through specification of a repeatability for the bull and then determination of the bull's PD as a function of his breeding value and repeatability. Additionally, bulls in a population generally have different repeatabilities, and bulls with lower repeatabilities generally have estimates of breeding value that are more variable than higher repeatability bulls.

The following procedure was developed to estimate PD's for the seven transmitted traits from breeding values and repeatabilities of bulls. First, the operator of the program is asked to specify an average repeatability desired for each trait. For example, in this simulation the average repeatability for PD Milk is 75%. Second, a Standard Normal deviate is applied to select a repeatability for each bull, centered around the desired mean for repeatability. Thus, each bull has a different repeatability, and PD's

Table 7. Literature estimates of genetic SD used for simulating breeding values.

Trait	Estimate	Source[1]
Milk yield, kg	471	(89)
Fat percent, %	.272	(89)
Protein percent, %	.155	(89)
SCC, Log_2	.257	(13)
Dairyness[2], #	2.75	(30)
Stature, #	2.69	(30)
Udder depth, #	2.22	(30)

[1] Source of estimate from literature.

[2] Scale for linear type traits is 1 to 50 points.

for the bulls can be estimated to differing degrees of precision. Finally, PD's are estimated using the following equation:

$$PD_{ij} = \frac{BV_{ij} + \sqrt{1 - R_{ij}}\, G_i D}{2}$$

where

$PD_{ij} =$ estimate of the Predicted Difference of the i^{th} trait on the j^{th} bull

$BV_{ij} =$ breeding value for the i^{th} trait on the j^{th} bull

$R_{ij} =$ repeatability for the i^{th} trait on the j^{th} bull

$G_i =$ genetic SD for the i^{th} trait

$D =$ an uncorrelated Standard Normal deviate

From this, it can be seen that the bull's PD is deviated from his true breeding value, with a measure of reliability included from repeatability, and a source of error included from the random number selected. As repeatability approaches 1, the term $\sqrt{1 - R_{ij}}$ approaches 0, and the value of the bull's PD approaches one-half of his breeding value. As repeatability approaches 0, the term $\sqrt{1 - R_{ij}}$ approaches 1, and the bull's PD is estimated as one-half of his true breeding value plus one-half of a Standard Normal deviate times the genetic SD (from Table 7) for the trait. Average repeatabilities (with SD) used for the traits were as follows: Milk yield, fat percent, and protein percent (75%, 15%), SCC (30%, 8%), and dairyness, stature, and udder depth (55%, 12%). Repeatabilities were truncated so as not to be greater than .99 or less than .01. Repeatabilities were also specified for the non-transmitted traits expected percent difficult births in heifers (35%, 5%), PD Type (55%, 12%), and fertility (40%, 5%). Repeatabilities were not used in prediction of these values because the traits do not have breeding value estimates in this simulation. Repeatabilities were used for all traits measured on bulls to obtain estimates of the number of daughters and number of herds in the evaluation, but none of these was used in this project.

PD's for all seven transmitted traits are calculated in the manner described above. The PD's for fat and protein yield were estimated using the following equation:

$$\mathrm{PD}_{ij} = (\text{Base Milk} + \text{PD Milk}_j)(\text{Base Percent}_i + \text{PD Percent}_{ij})$$
$$- (\text{Base Milk x Base Percent}_i)$$

where

$\mathrm{PD}_{ij} =$ the i^{th} PD on the j^{th} bull, where

i = 1 if prediction is for PD Fat, and i = 2 if prediction is for PD Protein

Base Milk = 6800 kg

Base Percent = 3.7 if i = 1, and 3.2 if i = 2

PD Milk $_j =$ PD Milk of the j^{th} bull whose PD Fat and Protein is predicted

PD Percent $_{ij} =$ PD Percent of the i^{th} trait on the j^{th} bull

Several other traits are calculated on bulls from information collected on the bulls, but are not estimated directly from breeding values. These traits are the expected percent difficult births in heifers, fertility, PD Type, PD Dollars, PD Dollars for Protein, and semen price. Expected percent difficult births and fertility have an underlying genetic basis, but this basis is not considered in the simulation. The PD Type, PD Dollars, and PD Dollars for protein are estimated based on data from the transmitted traits. Semen price is based on PD Dollars and PD Type. PD Dollars and PD Dollars Protein are calculated as outlined in (56). PD Type is not used in this simulation, except as a component of semen price. PD Type is estimated by the following equation:

$$\text{PD Type} = .50 + .7(.355 \text{ PD Stature} + .17 \text{ PD Dairyness} + .135 \text{ PD Udder Depth})$$
$$+ .3(.75\ \mathrm{D}),$$

where PD Type is the bull's Predicted Difference for type, PD Stature, PD Dairyness, and PD Udder depth are Predicted Differences for stature, dairyness, and udder depth, and D is an uncorrelated Standard Normal deviate. This formula implies that the desired mean PD Type is .5, 70% of the difference from this mean is due to linear type traits, and 30% of the difference from this mean is random. Price of a bull's semen is based on the following equation: Price = −4.50 + .053 PD Dollars + 10.98 PD Type. Prices are restricted to be greater than $2 in all cases. The expected percent difficult births in heifers is predicted as a correlated trait with stature. The phenotypic correlation between stature and calving ease in Holstein AI bulls was .27 from the last available USDA AI Sire Summary (July, 1988). This correlation, and the Standard Normal deviate used to create the bull's breeding value for stature, were used in the following formula to predict the expected percent difficult births in heifers:

$$B_i = .09 + .02(.27N_i + \sqrt{1 - .27^2}\,D)$$

where

$B_i =$ average percent difficult births of heifers mated to the i^{th} sire

$N_i =$ Standard Normal deviate used to create the breeding value for stature of the i^{th} sire

$D =$ an uncorrelated Standard Normal deviate

Mean expected percent difficult births in heifers was set at 9%, with SD 2%. This agrees with data of active AI Holstein bulls from the July, 1988 AI Sire Summary. The N and D combine in the above formula to form a new Standard Normal deviate that is correlated to N with the specified correlation. The result of N and D combining to form a new Standard Normal deviate was verified by Toro (85). Values of expected percent difficult births in heifers were restricted so that the minimum value was 1%.

A value estimating fertility of bulls was included in the model, although fertility as a trait of the bull was not evaluated in this simulation. Heat detection and conception rates in herds assume all bulls have the same fertility. Fertility was included because future analyses using the simulation may investigate relationships of differences in bull fertility with herd management programs. Fertility was calculated as an uncorrelated trait with mean 0 and SD .04 to represent the current Estimated Relative Conception Rate (ERCR) data published by the Raleigh DRPC (McGilliard, M. L., 1988. Personal communication).

Selection of bulls to be used in the simulation can be based on several indices. The simplest indices select bulls on the highest values of single traits or simple combinations of traits. For the herd study, bulls were selected on an index representing PD Dollars. This index estimated PD Fat as PD Milk times PD Fat Percent, and included PD Milk and PD Fat in the estimation of PD Dollars as in (56). In retrospect, selection based on PD Dollars using a more accurate estimate of PD Fat would be more desirable, and was done in the cow study. It was desired to have 20 bulls available for matings each year, and these bulls would represent the top 16.7% (1 out of 6) of the population based on the index used. Therefore, 120 bulls were generated each year, with the top 20 index bulls being retained for matings to cows and heifers. These bulls were mated randomly to all cows and heifers in the herds unless the option was specified to breed heifers only to calving ease bulls. For this option, only bulls with estimates for percent difficult births in heifers of less than 7% (mean minus one SD) were used in matings to heifers, with all bulls mated randomly to cows.

Table 8 lists means, standard deviations, minimum, and maximum values for breeding values for the seven transmitted traits of the 420 bulls used in the simulation of the herd study. The 420 bulls represent 20 bulls used for matings and creation of calves and yearlings in the initial herd, plus 20 bulls per year used for matings over 20 yr of simulation. Table 9 lists means, standard deviations, minimum, and maximum values for Predicted Differences on the 420 bulls used in the herd study, and Table 10 lists the same measurements for the 40 bulls used in the cow study. The cow study used 40 bulls because animals born in the first year of data collection could have sires from that year or the previous year.

Table 8. **Means, SD's, minimum, and maximum breeding values of transmitted traits for 420 bulls used in the herd simulation.**

Trait	Mean	SD	Minimum	Maximum
Milk yield[1], kg	1215	485	49	2810
Fat percent, %	-.08	.27	-.9	.7
Protein percent, %	-.05	.16	-.5	.5
SCC, Log $_2$	.168	.24	-.68	.77
Dairyness[2], #	.50	2.75	-8.18	8.92
Stature, #	1.82	2.48	-6.61	8.78
Udder depth, #	-.31	2.21	-8.08	5.84

[1] Large values for breeding value milk are due to an accumulation of genetic trend and selection over 20 yr.

[2] Range for linear type traits is 1 to 50 points.

Table 9. Means, SD's, minimum, and maximum values for predicted differences on 420 bulls used in the herd simulation.

Trait	Mean	SD	Minimum	Maximum
PD Milk[1]	682	225	272	1527
PD Fat[1]	21.0	12.62	-19	62
PD Fat Percent	-.056	.15	-.46	.37
PD Protein[1]	19.3	9.08	-5	50
PD Protein Percent	-.034	.09	-.30	.18
SCC	.114	.148	-.328	.474
PD Dairyness	.28	1.59	-4.50	5.47
PD Stature	1.26	1.45	-2.84	5.81
PD Udder Depth	-.25	1.33	-4.42	2.99
Percent Difficult Births	.09	.02	.01	.15
PD Type	.81	.53	-.61	2.39
Fertility	-.002	.03	-.11	.11
PD Dollars[1]	163	64.68	-17	386
PD Dollars Protein[1]	156	70.04	-56	388
Price[1]	13.21	6.70	2	33.65
Repeatability - Milk	.73	.15	.36	.99
Repeatability - SCC	.30	.08	.08	.50
Repeatability - Type	.55	.11	.20	.88
Repeatability - Fertility	.40	.05	.24	.56
Repeatability - Percent Difficult Births	.34	.05	.21	.49

[1] Values for production traits different from zero are due to an accumulation of genetic trend and selection over 20 yr.

Table 10. Means, SD's, minimum, and maximum values for predicted differences on 40 bulls used in the cow simulation.

Trait	Mean	SD	Minimum	Maximum
PD Milk[1]	344	210	-86	1082
PD Fat[1]	17.8	7.79	3	33
PD Fat Percent	.076	.17	-.4	.38
PD Protein[1]	12.0	6.40	-1	30
PD Protein Percent	.016	.10	-.20	.23
SCC	.153	.128	-.079	.428
PD Dairyness	.21	1.39	-2.98	2.66
PD Stature	1.48	1.34	-1.39	3.97
PD Udder Depth	-.26	1.28	-3.45	2.34
Percent Difficult Births	.09	.02	.05	.12
PD Type	.94	.45	-.11	1.85
Fertility	.002	.03	-.05	.06
PD Dollars[1]	108	32.58	70	198
PD Dollars Protein[1]	110	36.15	60	205
Price[1]	11.65	5.36	2	26.31
Repeatability - Milk	.73	.17	.40	.99
Repeatability - SCC	.28	.09	.09	.50
Repeatability - Type	.59	.12	.34	.82
Repeatability - Fertility	.41	.04	.31	.50
Repeatability - Percent Difficult Births	.36	.05	.24	.49

[1] Values for production traits different from zero are due to an accumulation of genetic trend and selection.

The minimum breeding value for bulls in the herd simulation is 49 kg (Table 8), whereas the minimum PD Milk for the same bulls is 272 kg (Table 9). This discrepancy exists because bulls were selected on an index of PD Milk and PD Fat, and not on actual breeding value. Although breeding value milk is highly related to PD Milk, the effects of gene segregation, combined with inaccurate knowledge of the estimation of PD Milk (due to repeatability), cause PD Milk to be an imperfect measure of half the breeding value for milk.

Simulation of Initial Herds

It is difficult to identify the starting point with a herd of dairy cattle because of the continuous nature of biological functions of individual cows. A herd of dairy cattle consists of animals in all stages of their life cycle at any given point in time, ranging from day old calves to yearlings, young cows, and old cows. Yearlings and cows are at different stages of their reproductive cycle, as certain percentages of them are open, bred, pregnant, and due to calve. These cattle also differ in age, size, body condition, milk yield, and have different nutrient requirements.

The objective of this section is to describe generation of the initial herd (or herds) of cattle at a specific point in time with characteristics of an ongoing herd. It is not practical to begin the simulation many years prior to the desired starting date and develop a herd over time as this is computationally intensive and slow. Rather, programming and equations must be developed to create a herd and the cows within it instantaneously. An explanation of development of the model that creates the initial herds and cows will be presented chronologically.

One of the more important aspects of the simulation is the decision of what information should be collected and stored. The type of information collected on cows partially determines programming requirements. A record format was developed to collect information on cows as they progress through their lifetime, mimicking information recorded through the DHIA system. The record format is created at birth and is used throughout the cow's entire lifetime. Following is a description of information contained in a cow record.

Identification data recorded in the cow's record include her identification number, her herd, sire, dam, maternal grandsire, and service sire. A code is included in the identification number that indicates the year of birth of the cow. Only the most recent service sire information is retained. The cow's birth date is stored, as is current information for date calved, date bred, date dry, date due, lactation number, current status (open, bred, pregnant, or dry), number of services this lactation, and current body weight. Information that does not apply to heifers is left blank. Reproductive data stored in the record are days in milk, days open, days pregnant, days dry, days open in the previous lactation, days dry in the previous lactation, calving interval, days to first heat, days to first breeding, and number of heat cycles in this lactation.

Health related data, stored for the current lactation only, are whether or not dystocia occurred with this calving, whether or not other reproductive problems occurred, whether the cow becomes permanently sterile, which (if any) diseases occurred and when they occurred, the number of cases of mastitis observed, and kg of milk discarded during the lactation. Cumulative income and expense are recorded on heifers until their first calving, when that value is transferred to lifetime net income. Income and expenses are accumulated for the duration of each lactation starting with freshening. At the end of each lactation (which is the next freshening date or removal) the accumulated totals are added to the lifetime net income, with lactation income and expense reset to zero.

With respect to production, the cow's breeding value, permanent and temporary herd effects, and permanent and temporary cow effects are stored. Temporary herd and cow effects change each time the cow is fresh. Values for equation coefficients used to estimate daily milk yield are also stored. Production variables recorded are cumulative milk, fat, and protein yield, 305 d actual milk, fat, and protein yield, and 305-2X-ME milk, fat, and protein yield. Finally, if an animal leaves the herd either involuntarily or voluntarily, the reason for leaving the herd is stored along with the date she left the herd. These are not all of the variables collected in the cow record, but represent the most important variables.

The initial simulated herds are created as of the end of the first year of simulation. The first characteristic simulated is the age structure of the herd. Research by Andrus et al. (3) investigated the age distribution and life expectancy of cows in Iowa dairy herds in 1970. Their data involved age groups of cows from 1 to greater than 10 yr, but did not specify this distribution by lactation number. It was desirable to have the age distribution in the simulation by lactation number rather than age, although these measures are similar. From Andrus' work, and assuming that age groups 1 to 2 yr were first lactation, age groups greater than 10 were tenth lactation, and all other age groups equalled their lactation number, the age distribution for Iowa dairy herds is shown in Table 11.

An approximation to the Andrus age distribution was developed using the Negative Exponential distribution presented in the Review of Literature. The equation for the Negative Exponential distribution is $\frac{1}{\mu} e^{-i/\mu}$, where i is the number of lactation classes desired (10) and μ is 3.0. When $\mu = 3.0$ is used the distribution is nearly identical to that of Andrus (Table 11). These values were used to create the initial age distribution by lactations in this simulation. Use of the Negative Exponential distribution could allow one to choose a different age distribution if desired. Lowering μ from 3.0 to 2.5 increases

Table 11. Expected and simulated frequencies of age distribution, by lactation.

Lactation	Frequency (%)		
	Andrus et al. (3)[1]	Predicted[2]	Simulated[3]
1	.2818	.294	.297
2	.2146	.211	.214
3	.1639	.151	.151
4	.1256	.108	.109
5	.0874	.077	.070
6	.0563	.056	.058
7	.0336	.040	.039
8	.0182	.029	.024
9	.0097	.020	.021
10	.0089	.015	.017

[1] Probabilities of age distribution estimated by Andrus et al. (3) were in years of age and not lactations. Years 1-2, and 2-3 were grouped into lactation 1, and years 10 and greater were grouped into lactation 10. It was assumed years of age were equivalent to lactation number.

[2] A Negative Exponential distribution with mean 3.0 was used to predict probabilities of lactation distribution.

[3] Probabilities estimated from 1000 simulated lactation numbers.

the percentage of first lactation animals in the herd from 29% to 33%, which also reduces the number of older cows. Figure 8 illustrates the relationship between the value of μ chosen and the simulated age distribution of the herd. While selecting a value for μ sets the distribution for age structure in a herd, it does not actually set the lactation number for individual cows, which will be done later.

After the distribution for age is set, correlated Standard Normal distributions are sampled to determine permanent and temporary herd effects for traits. Permanent and temporary herd effects are assigned for the same seven transmitted traits as for bulls: Milk yield, fat percent, protein percent, SCC, dairyness, stature, and udder depth. These traits are called transmitted traits for bulls because they are genetically based and bulls do not influence production or other traits of their daughters except through their breeding value. For cows, cow and herd effects are not genetic but do have an effect on production and other traits. They are still called transmitted traits, although only a portion of the trait representing the cow's breeding value is actually transmitted.

All cows in a herd have the same permanent herd effects for all traits, and all cows that calve in a given year have the same temporary herd effects for the traits. Thus, the permanent herd effects need only be calculated once, and the temporary herd effects need only be calculated once per year. When choosing correlated deviates for permanent and temporary herd effects, environmental correlation matrices were used (Tables 5 and 6), which accounts for phenotypic and genetic correlations among the traits. Assignment of permanent and temporary herd effects assumes the mean and SD of their distribution are known. For the seven transmitted traits in the initial herds, means for the permanent and temporary herd effects are assumed zero with SD presented in Table 12.

At this time cows are assigned permanent and temporary herd effects, plus breeding value, and permanent and temporary cow effects for the seven transmitted traits. For each trait, the permanent herd effect is constant for all cows in a herd and reflects the

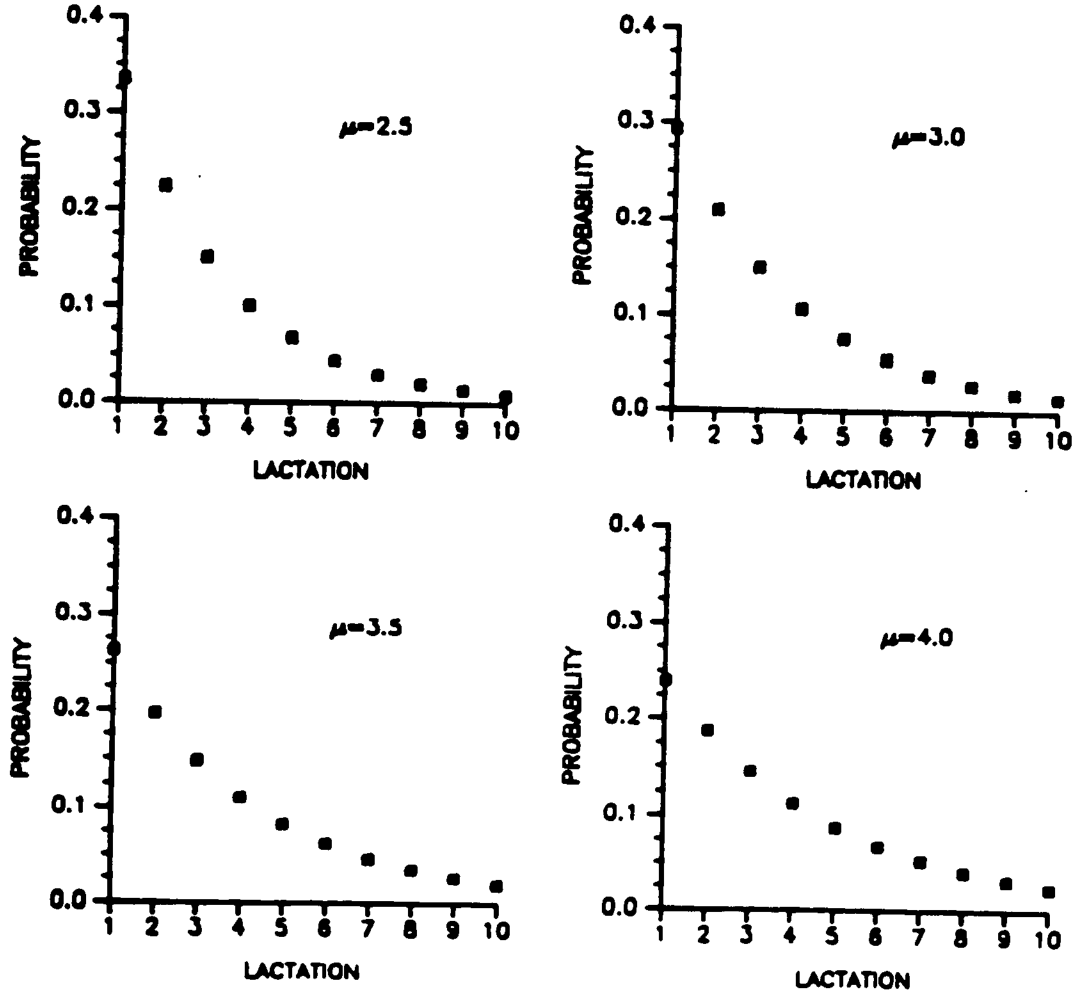

Figure 8. Examples of the Negative Exponential distribution, used to predict lactation number, with means of 2.5, 3.0, 3.5, and 4.0.

Table 12. Literature estimates of standard deviations used for simulating permanent and temporary environmental effects for herds and cows.

Trait	Effect[1] Permanent Herd	Temporary Herd	Permanent Cow	Temporary Cow	Source[2]
Milk yield, kg	697	489	471	666	(89)
Fat percent, %	.259	.182	.111	.192	(89)
Protein percent, %	.162	.114	.098	.120	(89)
SCC, Log_2	.522	.522	.424	.757	(13)
Dairyness[3], #	4.92	4.02	2.42	2.65	(30)
Stature, #	4.26	3.48	3.48	3.25	(30)
Udder depth, #	4.90	4.00	2.90	2.68	(30)

[1] Total herd phenotypic SD for SCC, dairyness, stature, and udder depth were known, but partitioning of permanent and temporary effects was not. Partitioning of permament and temporary herd effects for these traits was estimated.

[2] Source of estimate from literature.

[3] Scale for linear type traits was 1 to 50 points.

part of the cow's yield or other characteristics that does not change due to constant herd and management conditions. Temporary herd effects change yearly for all cows in the herd, and are due to things such as weather conditions and feed quality. Permanent cow effects are constant for a cow throughout her lifetime, for instance a calf that suffers illness as a young calf and never fully recovers. Temporary cow effects are peculiar to the cow's current lactation, and could be due to the occurrence (or lack of occurrence) of specific diseases. Environmental correlation matrices, means, and phenotypic standard deviations are utilized in the creation of the permanent and temporary herd and cow effects. Breeding value for cows is estimated similarly to breeding value estimation for bulls, incorporating the genetic correlations among the traits, mean breeding values, and genetic SD of the traits. Mean breeding values of all traits for cows in the initial herds are zero. Genetic SD for the traits are in Table 7. For all traits within each effect, a correlated Standard Normal deviate is selected and multiplied by the corresponding SD for the trait to obtain values for all traits and all effects. Genetic SD were estimated from phenotypic within herd SD reported by Van Vleck (89) by dividing the phenotypic SD into parts according to heritability, repeatability, and remaining variation. Heritability and repeatability used for milk are .25 and .50, respectively. Values used for fat percent are .60 and .70, and for protein percent, .50 and .70. Heritabilities are from Van Vleck (89), and repeatabilities are estimated.

The random number used to estimate the permanent herd effect for milk yield, and the set of correlated random numbers used to estimate the temporary herd effect for all traits are stored for later use. The random number for the permanent herd effect is used to correlate growth of heifers to the permanent herd effect, as herds with high yield usually raise larger heifers. This agrees with Heinrichs and Hargrove (39). Random numbers for temporary herd effects are stored for use in creating correlations with the next set of temporary herd effects. This reduces year to year variability in temporary effects without reducing the phenotypic SD for the traits. Some users of this program have felt that the McGilliard and Edlund (51) simulation generates too much year to year fluctuation in temporary herd effects without this correlation.

The distribution of age structure of the herd identifies the percentage of cows in each lactation, but does not assign a lactation number to individual cows. The assignment of a lactation number starts with developing the cumulative distribution of lactations from the age structure distribution. As each cow is created in the simulation, a Uniform deviate is sampled, and the cow's current lactation is determined from this value.

Creation of a milking age cow in this simulation assumes that the cow has freshened during the past 12 mo. Data from Norman et al. (57) summarized the number of freshenings by month for 3,386,876 fresh dates in US dairy herds. The frequency of freshenings by month are in Table 13 for the Norman data. Table 13 also contains data for 1000 simulated freshenings, used for testing the simulation model and comparing to the field data. Month of freshening is estimated by converting the frequencies from the Norman data to a cumulative distribution, and then sampling a Uniform deviate to determine month of freshening for each cow. Because the initial herds are created as of the end of the first year, and since all cows in the herd were required to be fresh within the previous 12 mo, year of freshening is the same for all cows. The precise definition of a year in this simulation covers October 1 of one year to September 30 of the next. This is not important to this simulation, but is retained for future use in management programs as October 1 normally indicates the end of harvest, and temporary effects due to feed quality and quantity could be assigned using these dates. The actual day of freshening (within month fresh) is not as important as the estimation of month fresh. Day fresh was assumed Uniformly distributed over the range 1 to 28 d to alleviate problems with the variable number of days in a month, but still give cows an individual day fresh.

Specification of month, day, and year fresh indicates the calving date of the cow. A calf was created at this point in the simulation representing the result of that freshening. The calf's dam is the cow being created, and a sire is selected randomly from all bulls available for matings in the initial year of the simulation. The calf's birth date is assigned as the cow's freshening date, and birth characteristics are assigned to the calf. If the calf is alive and is a female, data representing characteristics of the calf are updated representing movement of the calf through time to the end of the first year. This length of time will be variable, depending on the freshening date of the cow. Characteristics assigned at birth are sex of the calf, whether or not the calf was born alive; the permanent herd effects, permanent environmental effects, and breeding values for the seven transmitted traits; a Pedigree Index for milk yield, and birth weight. Births of bulls and heifers are equally likely, and 10% of all calves born are dead at birth. This value assumes all deaths through 1 yr of age occur at birth, which is unimportant in the initial herds since no financial information is collected. Bull calves born alive are assumed sold and are removed from the initial herd. Permanent herd effects are assigned to the calf, and permanent cow effects for the calf are assigned from a distribution with mean zero and SD from Table 12. Breeding values for calves are assigned with the following equation:

$$BV_{ijk} = .5S_{ij} + .5C_{ik} + \sqrt{.5}\, D\, G_i$$

where

$BV_{ijk} =$ breeding value for the i^{th} trait on the calf with the j^{th} sire and k^{th} dam

$S_{ij} =$ breeding value for the i^{th} trait on the j^{th} sire

$C_{ik} =$ breeding value for the i^{th} trait on the k^{th} dam

$D =$ genetically correlated Standard Normal deviate

Table 13. Frequencies of cows calved by month of freshening, from data of Norman et al. (57) and simulation.

Month Fresh	Frequency	
	Norman et al. (57)[1]	Simulated[2]
January	.084	.089
February	.067	.076
March	.068	.071
April	.052	.049
May	.050	.042
June	.056	.051
July	.083	.085
August	.108	.122
September	.117	.128
October	.114	.096
November	.104	.085
December	.097	.106

[1] Frequencies for month of freshening estimated from 3,386,876 freshening dates.

[2] Frequencies estimated from 1000 simulated freshenings.

$G_i =$ genetic SD for the i^{th} trait

This formula implies that the breeding value for all traits of the calves in this simulation are created as one-half of their sire's plus one-half of their dam's breeding values, plus an effect of gene segregation that results from the specific mating of the sire and dam. Genetic correlations among the traits are accounted for with the correlated deviates. The estimate of Pedigree Index for milk yield is one-half of the sire's plus one-half of the dam's breeding value for milk yield (ignoring gene segregation). This estimates the Pedigree Index in a simple manner without incorporating actual records of relatives into a formula. Pedigree Index will be used in the simulation for the purpose of culling pregnant heifers when excess pregnant heifers exist. Heifers that are culled will have the lowest values for Pedigree Index among a group of heifers close to freshening. Temporary herd and cow effects are assigned at first freshening.

Birth weight of bull calves is not important since dystocia is not simulated in the initial herds, and though bull calves are sold, income from the sale is not recorded. Birth weight of heifers is assumed Normally distributed with mean 40.27 kg and SD 2.0 kg from the work of Heinrichs and Hargrove (39). All calves that died in the first year were assumed dead at birth to make computations easier. Also, calves less than 1 yr old were too young to breed, so the only characteristics of live heifers to be updated at the end of the first year were the calf's age and body weight. Age of the calf in days was the date at the end of the year minus the calf's birth date. Age divided by 30.4 estimated the calf's age in months. Updating the calf's body weight to the end of the year requires a point estimate of the calf's weight at her current age using the following equation from Heinrichs and Hargrove (39): $BWT = 19.87A + .285A^2 - .0119A^3$, where BWT is the calf's estimated body weight at the end of the initial year of the simulation, and A is the calf's age in months at the end of the initial year. To create variability about this value

10% of the estimated body weight was multiplied by a Standard Normal deviate that was correlated .2 to the permanent herd effect for milk yield. This implies that as heifers get older and heavier their body weight is more variable, and that heifers from herds of high milk yield grow faster and are larger at calving.

If the simulated cow that produced the calf described above was in her second or greater lactation, then a yearling animal was also generated from this cow. Yearlings are created similarly to calves, except that they are born 12 to 14 mo earlier depending on the cow's calving interval, their current weight is heavier because they are older, and some of them are old enough to be bred or pregnant. It is assumed yearlings are not old enough to have calved, because if they had calved then they would be first lactation heifers in the herd and not yearlings. Pregnant yearlings from cows that had calves at the earliest possible dates in the initial year would be ready to calve starting in the first month of the next year.

Identification, selection of a sire for yearlings, and assignment of breeding value, the permanent herd effect, and the permanent cow effect are similar to the assignment of these values for calves. Date of birth is assigned to be 370 ± 10 d prior to the current cow's freshening date. This interval is not allowed to be less than 340 d. Male and female calves are equally likely, and the death rate for yearlings is 15% from birth to first freshening. The death rate included removal for all causes of death, plus removal for infertility through first calving. Current body weight is estimated similarly to that of calves, except yearlings are older and larger. Maximum body weight of yearlings ready to freshen is 540 kg.

The only remaining characteristic of yearling heifers to be updated is pregnancy status, and determination of a service sire for heifers that are bred. Yearlings are not allowed to be bred until they are 460 d old. For yearlings greater than 460 d old, the following procedure is used to determine whether the heifer was not bred, bred but not pregnant, or pregnant. First, the number of days from the time when the heifer reaches 460 d old to the time when she would become pregnant is estimated using the cumulative distribution shown in Table 14. This is the expected distribution of time to conception if all heifers are cycling at 460 d of age, the cycle length is 21 d, conception rate in heifers is assumed to be 60%, and heat detection rate is 50% for first service, 56% for second service, and 67% for all later services. All heifers are assumed pregnant by 670 d, or 210 d after they are old enough to begin breeding. Data in Table 14 are listed in classes, but actual days to the projected date of conception added a Standard Normal deviate with SD 3 d to that value. The projected date of conception is the heifer's date of birth plus 460 d plus the number of days from 460 d to projected conception.

A heifer is considered not ready to breed if she is less than 460 d old. If the heifer is greater than or equal to 460 d old and the projected date of conception is later than the ending date of the first year, then the heifer is assumed bred or ready to breed but not yet pregnant. The number of services is assigned according to the data in Table 15 for heifers not pregnant. Heifers with 0 services are considered ready to breed but not bred. Heifers with greater than 0 services are assumed bred and assigned a service sire from bulls available for matings in the first year. If the heifer is greater than or equal to 460 d old and the projected date of conception is less than the ending date of the first year then the heifer is assumed pregnant. Pregnant heifers are assigned a number of services from data in Table 15 for pregnant heifers based on the number of days from 460 d of age to conception. Date bred and date due are assigned, with gestation length assumed to be 280 ± 6 d. A small percentage of the oldest heifers had projected calving dates before the end of the initial year, i.e., within the last 2 wk. For these animals only, the due date was set to be the first day of the next year. Service sire is selected at random from available bulls.

Table 14. **Cumulative distribution of the number of days after 460 d of age when conception occurs in yearling heifers.**

Number of days after 460 d	Cumulative Probability of Conception
10	.30
31	.54
42	.73
63	.84
84	.92
105	.95
126	.97
147	.98
168	.99
189	1.00

Table 15. Cumulative probability of number of services required for heifers with a specified number of days between 460 d old and age at breeding.

Interval After 460 d	Maximum Services	Number of Services 0	1	2	3	4
		Pregnant Heifers				
< 21 d	1	.00	1.0	--	--	--
21 to 41 d	2	.00	.29	1.00	--	--
42 to 62 d	3	.00	.10	.31	1.00	--
> 62 d	4	.00	.09	.18	.45	1.00
		Heifers Ready to Breed				
< 41 d	1	.30	1.0	--	--	--
42 to 82 d	2	.10	.34	1.00	--	--
83 to 145 d	3	.04	.13	.41	1.00	--
> 145 d	4	.04	.08	.19	.41	1.00

The number of calves and yearlings created as animals born to cows in the current herd may underestimate the actual number of calves and yearlings needed in a herd. This is because more animals actually freshen in a year than the total number of cows in the current herd. To ensure enough heifers are available to maintain adequate replacement rates, extra calves and yearlings are created in the initial year. The method used to create characteristics of these animals is the same as previously described, except these animals have unidentified dams with mean breeding value zero and SD of breeding value as stated in Table 7. The number of extra calves and yearlings equals one-half of the total number of cows in the current herd, with 25% of these animals assigned as calves and 75% of them assigned as yearlings. Since the dams of these animals are unknown, their birth dates must be generated by assigning a freshening date to an imaginary dam, and using this date to estimate birth date of the calves and yearlings as described previously. The number of calves and yearlings added to the herd is much smaller than one-half of the herd size, as the calves and yearlings are subject to the same probabilities of sex ratio and death as other youngstock created earlier.

After calves and yearlings are created, the date of birth and current days in milk are calculated for the cow. Days in milk are assigned as the difference between the ending date of the first year and the cow's freshening date. All cows receive fresh dates when they are created, so all cows will have a value for days in milk. The value for days in milk may be updated later if the cow is determined to be pregnant long enough to be dried off. The birth date of a cow can occur anytime from 23 mo prior to the current date fresh for first lactation heifers to 147 mo prior to the date fresh for tenth lactation cows. These dates represent an average date of first calving of 27 mo, and a 13 mo calving interval. For the 10 lactation groups, the days of age at current freshening are assigned as a mean age at freshening in days for that lactation group with SD 40 d. Mean age at freshening for the 10 lactations are: Lactation 1 = 816 d, 2 = 1210 d, 3

= 1603 d, 4 = 1996 d, 5 = 2390 d, 6 = 2783 d, 7 = 3176 d, 8 = 3570 d, 9 = 3962 d, and 10 = 4356 d. Birth date is the date of freshening minus the number of days from birth to the current freshening.

Reproductive status of the cow is determined next. Cows less than 60 d in milk at the end of the first year are not eligible for breeding in that year. Determination of pregnancy status for the other cows is similar to that of heifers except different measurements are used to estimate time to projected conception. First, the number of days from calving to breeding are determined based on the cumulative distribution in Table 16. Data in Table 16 assume all cows are cycling, the cycle length is 21 d, conception rate is 45%, and heat detection rate at first breeding is 45%, at second breeding is 56%, and at later breedings is 67%. This would result in an average days open of about 127 d. Number of days from calving to breeding represents the days in milk of the animal when conception could take place, and could not occur before 60 d in milk. If the projected breeding date is before the end of the initial year the cow is assumed pregnant. Number of services required to obtain pregnancy is assigned according to the data in Table 17 for pregnant cows, based on their current days in milk. If the projected breeding date is after the end of the first year, the cow may or may not be bred but is not pregnant. Number of services is assigned from data in Table 17 for cows bred but not pregnant, also based on their days in milk. Cows can have up to 5 services while heifers can have up to 4 services.

Pregnant cows are assigned values for days open, days pregnant, and a due date. Gestation length is 280 ± 6 d. Cows are only allowed to freshen once in the initial year. Cows that are fresh in the first month of the year and have good reproductive performance could be due again near the end of the first year. If the due date is before the end of the initial year, then it is reset to the first day of the next year to avoid complications in the simulation model. Once a cow is confirmed pregnant, her maximum days in milk

Table 16. Cumulative distribution of the number of days in milk when conception occurs in cows.

Number of Days in Milk	Cumulative Probability of Conception
70	.20
91	.40
112	.58
133	.71
154	.80
175	.86
196	.90
217	.93
238	.95
259	.97
280	.98
301	.99
322	1.00

Table 17. Cumulative probability of number of services for cows with specified days in milk.

Days in Milk	Maximum Services	Number of Services 0	1	2	3	4	5
Pregnant Cows							
< 70 d	1	.00	1.0	--	--	--	--
71 to 91 d	2	.00	.30	1.00	--	--	--
92 to 112 d	3	.00	.12	.41	1.00	--	--
113 to 154 d	4	.00	.08	.23	.54	1.00	--
> 155 d	5	.00	.11	.22	.33	.55	1.00
Cows Ready to Breed							
< 60 d	0	1.00	--	--	--	--	--
61 to 102 d	1	.20	1.00	--	--	--	--
103 to 144 d	2	.075	.25	1.00	--	--	--
145 to 207 d	3	.03	.11	.28	1.00	--	--
208 to 291 d	4	.02	.07	.16	.30	1.00	--
> 292 d	5	.03	.06	.09	.16	.29	1.00

is set according to the equations of Oltenacu et al. (63). Setting the maximum days in milk allows a cow to have a dry period before her next calving. Maximum days in milk is a function of days open, and is different for lactation 1, 2, and 3 or greater. If the maximum days in milk is less than the cow's current days in milk, the cow's days in milk are reset to the maximum allowed days in milk, and the cow is dried off. Otherwise the cow is considered in milk at the start of the next year. If pregnant, a cow's number of days pregnant is calculated as her days in milk minus her days open. Cows that are dry and in their tenth lactation at the end of the initial year are removed from the herd.

Cows in different lactations have different body weights, and within a lactation a cow's body weight changes as the lactation progresses due to the effects of growth and milk production. Average body weight at calving for first, second, and third or later lactation cows was estimated as 500, 550, and 610 kg by (27). Body weight at calving is assumed Normally distributed within lactation with SD 30 kg. Body weight is adjusted from weight at calving to current weight using the procedure of Congleton (14). Daily weight gain in kg for the current lactation is calculated as: Daily gain = .001515 (650 - Initial weight). This implies that the mature weight of cows is 650 kg, and as the cows approach mature weight their daily gain approaches zero. Growth in first lactation heifers would be faster because of a larger deviation from 650 kg, and accounts for additional growth needed in heifers. Estimation of the cow's current body weight is her weight at calving plus the number of days from freshening to the current date times the daily gain. Maximum current weight for first lactation heifers is 570 kg, for second lactation cows is 630, and for mature cows is 700 kg.

In the simulation that moves cows and herds through time, milk yield is estimated daily and accumulated over all days of the lactation. However, in the initial year it is desired to estimate accumulated milk yield at the end of the year with a single calculation. The added computational speed of creating total milk yield to date with a single equation allows for the faster creation of herds. The Incomplete Gamma function described by Congleton and Everett (17) to estimate daily milk yield, also described in the Review of Literature, was: $Y_n = An^be^{-cn}$. To create cumulative milk yield in a single step, France and Thornley (32) presented an approximate integral to the Incomplete Gamma function. The integrated equation allowed for direct accumulation of milk yield from calving to the end of the year if the number of days in milk between the two dates is known. The approximate integral of the Incomplete Gamma function, as presented by France and Thornley is:

$$\ln Y_i = \ln(A\Delta t) + b \ln \bar{t}_i - c\bar{t}_i$$

where

$Y_i =$ cumulative milk yield of the i^{th} cow

A, b, and c = Gamma parameters, described in the Review of Literature

$\Delta t =$ length of period to estimate, in days

$\bar{t}_i =$ average length of period for the i^{th} cow.

Length of the period in the integral is the number of days from freshening to the end of the initial year. Since this equation is logarithmic, taking the exponential of ln Y_i gives the approximate cumulative milk yield of a cow with a given days in milk. This approximation is utilized to estimate cumulative milk yield only for cows in the initial herds. Values for the A, b, and c parameters vary according to lactation number, month fresh, breeding value, and environmental effects. Each of these effects is assumed additive, so adjustments to the parameters for the effects can be done sequentially.

The equation of France and Thornley (32) does not include an effect of pregnancy on milk yield, which will be added later as a multiplicative adjustment to cumulative yield. Oltenacu et al. (63) adjusted lactation yield for the effect of pregnancy by including d and g parameters in the Incomplete Gamma function. Oltenacu assumed that effects of pregnancy started at day 90 of pregnancy, so a value was assigned to d in his simulation. If the effects of pregnancy on yield are assumed to start at conception and gradually increase in magnitude as pregnancy progresses, the d parameter is zero and drops out of the equation. Early effects of pregnancy are assumed small, so d is set to zero in this simulation with effects of pregnancy starting at conception and gradually increasing during gestation. The reduction in yield due to pregnancy is the same, regardless of whether the reduction starts at day zero or day 90 of pregnancy, but the distribution of the reduction is different. To estimate cumulative milk yield for individual cows in this simulation, the A, b, c, and g parameters must be estimated.

Work of Congleton and Everett (17) estimated effects of lactation, month fresh, genetic merit, and environmental effects on the A, b, and c parameters of the Incomplete Gamma function. They published table values for adjustments to A, b, and c due to the effects mentioned above. Since the many levels of these effects are time consuming to fit and use much storage space, regression equations were developed to adjust the parameters based on the Congleton and Everett data. Because the adjustment for each effect is additive and assumed independent, the adjustments are done sequentially. Congleton and Everett estimated these parameters for first, second, and later lactations.

Within lactation, a fourth order regression equation on month fresh was fit for the A, b, and c parameters to develop equations predicting parameters for lactation and month of freshening. These equations include an intercept which includes the overall mean milk yield of all herds. Table 18 shows the intercept and coefficients used to estimate A, b, and c from the fourth order regression equation on month fresh within lactation for the Congleton and Everett data. These coefficients are presented to several decimal places, as the fourth order regression is very sensitive to changes in the coefficients, especially as the value for month approaches 12. Congleton (14) assumed that mature milk yield occurred in lactations 4 and 5. Lactations 1 and 2 have lower yield through adjustments in the parameters. Lactation 3 was assumed to have the same shape as lactations 4 and 5, but the A parameter was reduced 6% to reflect lower yield in third lactation cows. Similarly, in lactations 6 to 10 the A parameter is reduced by 1% per lactation to account for lower yield in older cows. Lactations 1 and 2 not only have less milk, but the shape of the lactation curves is different. The shape of the lactation curves for lactation 3 to 10 is the same, only the magnitude of A, and thus the height of the curve, change.

Values of the A, b, and c parameters predicted by fourth order regressions on the Congleton and Everett (17) data are listed in Table 19. These values are listed by lactation and month fresh for average cows in the base year of simulation. It was noted earlier that the equation of France and Thornley (32) was an approximate integral. Table 19 also contains estimates of 305 d actual milk yield using the integrated equation of France and Thornley, and 305 d actual milk yield using the Incomplete Gamma function of Congleton and Everett (17) accumulating yield daily over 305 d. The integrated equation consistently overestimates accumulated yield. However, the integrated equation is applied to all cows in the base year, differences between the two estimates are relatively small, and the increase in computational speed by integrating is large.

Adjustments for lactation and month fresh set the mean level of yield in all herds and seasons. Sequential adjustments of the parameters are also made to account for the effects of breeding value, permanent cow, temporary cow, permanent herd, and temporary herd. As production increases due to these effects, the shape of the lactation curve changes. The entire curve is raised, represented by increases in the A parameter. Also, shape of the lactation curve changes through differential modification of the b and c parameters, which increase the number of days to peak yield. Most of the magnitude of change in yield is through adjustment of the A parameter, which is in agreement with Grossman et al. (37).

Table 18. **Coefficients of fourth order regression equations used to predict adjustments to A, b, and c paramcters for lactation and month of freshening.**

Parameter	Intercept	Linear	Quadratic	Cubic	Quartic
			Lactation 1		
A	14.3925	-.73994427	.83082623	-.13401595	.00579396
b	.1557	.05018272	-.03025225	.00422482	-.00016917
c	.00273	.00116138	-.00053633	.0000668	-.000002478
			Lactation 2		
A	20.6265	-2.41259124	1.2762082	-.17523505	.00705875
b	.1743	.09816223	-.0415554	.0050919	-.000189589
c	.00444	.00187225	-.00070757	.0000796	-.00000275
			Lactation 3 to 10[1]		
A	16.2380	-1.44743505	.82530481	-.11053625	.0043113
b	.2641	.07340813	-.0294252	.00339578	-.0001194
c	.00546	.00133219	-.00045168	.0000453	-.000001375

[1] Mature yield was in lactations 4 and 5. Adjustments for differences in yield for lactation 3, and lactations 6 to 10 were made by multiplicative adjustment of the A coefficient. Adjustment for lactation 3 was 94% of lactation 4 and 5, and for lactations 6 to 10 A was reduced by 1% per lactation from Congleton (14).

Table 19. Expected 305 d yield of base year herd average cows with 305 d open, by lactation and month of freshening.

		Coefficients[1]			Milk Yield (kg)		
Lactation	Month Fresh[2]	A	b	c	Integrated[3]	Accumulated[4]	CF[5]
1	1	14.355	0.1797	0.00342	6414	6159	1.323
1	2	15.257	0.1662	0.00340	6385	6163	1.322
1	3	16.501	0.1343	0.00299	6267	6092	1.338
1	4	17.632	0.0995	0.00244	6116	5988	1.361
1	5	18.333	0.0727	0.00193	6001	5906	1.380
1	6	18.424	0.0610	0.00161	5972	5888	1.384
1	7	17.867	0.0676	0.00155	6040	5939	1.372
1	8	16.762	0.0912	0.00176	6179	6034	1.351
1	9	15.346	0.1269	0.00221	6328	6123	1.331
1	10	13.999	0.1654	0.00277	6428	6164	1.322
1	11	13.237	0.1936	0.00330	6462	6165	1.322
1	12	13.716	0.1942	0.00356	6446	6167	1.321
2	1	19.322	0.2358	0.00568	8113	7920	1.029
2	2	19.617	0.2421	0.00594	8165	7998	1.019
2	3	20.715	0.2169	0.00561	7991	7861	1.037
2	4	21.987	0.1794	0.00499	7717	7621	1.069
2	5	22.976	0.1442	0.00434	7466	7392	1.102
2	6	23.392	0.1214	0.00383	7329	7259	1.123
2	7	23.115	0.1166	0.00357	7348	7260	1.122
2	8	22.195	0.1306	0.00362	7513	7383	1.104
2	9	20.852	0.1599	0.00396	7769	7581	1.075
2	10	19.474	0.1964	0.00450	8025	7782	1.047
2	11	18.619	0.2274	0.00510	8186	7920	1.029
2	12	19.013	0.2358	0.00554	8154	7933	1.027
4,5	1	15.510	0.3114	0.00638	8553	8188	0.995
4,5	2	15.829	0.3185	0.00666	8677	8335	0.978
4,5	3	16.688	0.3016	0.00650	8602	8298	0.982
4,5	4	17.683	0.2737	0.00611	8415	8149	1.000
4,5	5	18.511	0.2454	0.00563	8217	7975	1.022
4,5	6	18.976	0.2240	0.00519	8086	7851	1.038
4,5	7	18.983	0.2142	0.00489	8068	7819	1.042
4,5	8	18.543	0.2178	0.00477	8168	7885	1.033
4,5	9	17.766	0.2335	0.00486	8349	8019	1.016
4,5	10	16.871	0.2575	0.00516	8546	8169	0.998
4,5	11	16.176	0.2828	0.00562	8678	8277	0.985
4,5	12	16.105	0.2998	0.00617	8658	8292	0.983

[1] A, b, and c coefficients adapted from Congleton and Everett (17).

[2] Months 1 to 12 correspond to January to December.

[3] Milk yield estimated by integrating the equation of Congleton and Everett (17), described on page 222 of (32).

[4] Milk yield estimated by summation of 305 d of individual yield, calculated using the model of Congleton and Everett (17).

[5] CF = mature equivalent correction factor for lactation and month of freshening. Mature equivalent records are relative to lactation 4 and 5, fresh at month 4 for accumulated yield. Lactation 3, and lactations 6 and greater have the same curve shape as lactations 4 and 5, but are reduced on a percentage basis to reflect yield changes by age group.

Adjustment of parameters of the lactation curve due to changes in yield is done in three parts. Breeding value and enviromental effects in Tables 7 and 12 are expressed on a mature equivalent basis, and the coefficients of Congleton and Everett are on an actual basis. The first step is to convert changes in production due to these effects to actual yield. Next, effects due to the overall average yield for all herds, permanent herd effects, and temporary herd effects are adjusted for. Finally, effects of breeding value, permanent cow, and temporary cow are added. Mature equivalent correction factors for lactation and month fresh were developed to convert the genetic and environmental effects to actual yield, and are used later to convert actual yield back to mature equivalent. Generation of mature equivalent correction factors is based on the data in Table 19 for accumulated yield. Month 4 of lactations 4 and 5 represents mature yield, i.e., the correction factor is 1.0. Correction factors for all other subclasses of lactation and month fresh are obtained by dividing the accumulated yield in month 4 of lactation 4 and 5 by accumulated yield in each class. These correction factors were fit to a fourth order regression equation within lactation 1, 2, and 3 or greater to estimate coefficients of a set of equations that would predict the correction factors. Coefficients of these equations are in Table 20.

The mature equivalent correction factors work well if herd average milk yield is near the population mean (7500 kg actual). As herd average yield becomes lower than 7500 kg, the mature equivalent correction factors tend to overestimate the relationship of mature equivalent milk with actual milk, and a reduction in the mature equivalent correction is necessary. Likewise, if herd average milk yield is above 7500 kg, the correction factors tend to underestimate the relationship, and the correction factors need to be increased. Adjustment of the correction factors is done in the following manner. First, the initial overall herd average milk yield is set by the operator of the simulation, and a ratio of the initial average to 7500 kg is calculated. If the ratio is less than 1, adjustment

Table 20. Coefficients of fourth order regression equations used to predict mature equivalent correction factors by lactation and month of freshening for milk yield.

Lacataion	Intercept	Linear	Quadratic	Cubic	Quartic
1	1.33758	-.03379	.018789	-.002669	.00011096
2	1.09331	-.100427	.040743	-.005025	.00019085
3 to 10[1]	1.05764	-.089947	.031324	-.003613	.00013203

[1] Factors are increased by 6% for lactation 3, and by 1% per lactation for lactations 6 to 10 to account for age deviations from mature yield.

for the correction factors is: Adjustment = (.875 (1-Ratio)) + Ratio. If the ratio is greater than 1, the the adjustment is: Adjustment = (.935 (1-Ratio)) + Ratio. Mature equivalent factors for all cows in all herds are adjusted by multiplying the adjustment by the correction factor.

Correction of the A, b, and c parameters of the Incomplete Gamma function for genetic and environmental effects are performed within lactation 1, 2, and 3 or greater based on actual yield. The first adjustment to the parameters adjusts for deviations in yield from the overall base herd average of 7500 kg, plus permanent and temporary herd effects. The permanent and temporary effects for milk yield are summed and converted to actual yield by dividing the mature equivalent effects by the mature equivalent correction factor, and then the deviation from the overall mean is added to the total. The magnitude of this total is converted into changes in the A, b, and c parameters by using a second order regression equation within lactation. Coefficients of these equations are presented in Table 21. Similarly, second order regression equations were developed to adjust the A and c parameters for deviations in breeding value, permanent cow effects, and temporary cow effects. The b parameter was not adjusted for cow effects, as data presented by Congleton and Everett (17) did not reveal a clear relationship between cow effects and the b parameter. Adjustment of cow effects was multiplicative for the A parameter, and additive for the c parameter. The cow effects were summed and converted to actual yield before use in the equations to predict changes in A and c due to deviated yield. Coefficients for the adjustment equations are in Table 22.

Average levels of fat and protein percent for the simulation are set by the operator of the program. For this simulation fat percent is 3.7% and protein percent is 3.1% Deviations from these values for individual cows are for breeding value, permanent and temporary cow effects, and permanent and temporary herd effects. These effects are added to the base level of fat and protein percent to obtain individual fat and protein

Table 21. Second order regression equations used to predict changes in A, b, and c parameters of the Incomplete Gamma function due to deviations from average herd yield, by lactation.

Parameter[1]	Intercept	Linear x 10^5	Quadratic x 10^7
		Lactation 1	
A	1.0091	9.618	-.1235
b	.00076	1.28	--[2]
c	.00009	-.021	--
		Lactation 2	
A	1.02	7.579	-.07374
b	-.0031	1.00	--
c	.000047	-.017	--
		Lactation 3 to 10	
A	1.0135	5.932	-.0721
b	-.0032	1.10	--
c	-.000009	-.019	--

[1] The equation predicted a multiplicative adjustment for A, adjustments for b and c were additive. .

[2] Only linear effects were fit for the b and c parameters.

Table 22. Second order regression equations used to predict changes in A and c parameters of the Incomplete Gamma function due to deviations in yield of cows within herd, by lactation.

Parameter[1]	Intercept	Linear x 10^4	Quadratic x 10^9
Lactation 1			
A	1.0183	1.50	-5.036
c	.000133	-.00217	--[2]
Lactation 2			
A	1.0182	.815	-7.274
c	.000145	-.00478	--
Lactation 3 to 10			
A	1.0038	.5676	-7.988
c	.000031	-.00602	--

[1] The equation predicted a multiplicative adjustment for A and an additive adjustment for c.

[2] Only linear effects were fit for the c parameter.

percent on cows within lactation. Fat and protein percent are not varied directly by lactation, but do change across lactations within cows because of the correlated response with milk yield.

Sufficient information has now been collected on cows such that milk, fat, and protein yield from freshening to the end of the initial year can be predicted. Cumulative actual milk yield is predicted using the integrated equation of France and Thornley (32) and parameters A, b, and c that are set in the simulation. Thus, cumulative yield takes into account individual differences in yield due to genetic and environmental effects through the A, b, and c parameters. If the cow is not pregnant, no adjustment is made to the cumulative yield. If the cow is pregnant, cumulative yield will be lower as nutrients are directed away from production and into development of the fetus. The amount of this difference is determined by the number of days pregnant at the end of the initial year.

The effect of pregnancy is a multiplicative adjustment less than 1, performed on cumulative yield at the end of the initial year. The adjustment is derived from the g parameter of the Incomplete Gamma function used by Oltenacu et al. (63). The present study eliminated use of the d parameter by assuming that d was zero, and the effects of pregnancy started at conception. This is a slightly different use of the g parameter than that of Oltenacu, so the g parameter must be modified depending on lactation and days open to obtain the desired effects due to pregnancy. Magnitude of the effect of pregnancy, in kg of reduced mature equivalent milk due to pregnancy, was estimated from work of Funk et al. (34) by comparing mature equivalent yield of cows with 305 d open to yield of cows with less than 305 d open. Modification of the g parameter changes the slope of the lactation curve, thus reducing production. Second order regression equations were used to predict changes in g for different lactations and days open to achieve differences in yield due to pregnancy that agree with those of Funk. These differences are relative to 305 d open, and are largest when days open are low because of the longer number of days pregnant between conception and 305 d in milk. When a cow conceives, the g parameter is set based on lactation number and days open with the second order regression equation listed in Table 23. For cows that are pregnant, cumulative yield is adjusted down by multiplying the cumulative yield by $\frac{1 + e^{-g\phi}}{2} + .00015dp$, where dp is the cow's number of days pregnant at the end of the initial year. The term $\frac{1 + e^{-g\phi}}{2}$ represents the average reduction in yield due to pregnancy. This average actually overestimates the reduction because of small effects early in pregnancy, so the term .00015 dp is included to adjust the average to a reasonable value.

Calculation of cumulative fat and protein yield assumes that a cow's fat and protein percent have a stage of lactation effect. Fat percent is usually higher than average early in lactation, drops to a low level at peak yield, and rises above average again later in lactation (21, 86). Total fat yield for a lactation using a variable fat percentage should be equal to total yield times the average fat percent. Because fat percent, and to a lesser degree protein percent, are influenced by stage of lactation, the yield curves for fat and protein are different than that of milk. Figure 9 illustrates the fat yield curve when fat percent deviates from average and the curve when fat percent is held constant during a lactation.

To estimate cumulative fat yield for a partial lactation, a second order regression equation was fit to cumulative fat yield by days in milk for a complete lactation. Then, 305 d milk yield was predicted and multiplied by the cow's average fat percent to estimate total fat yield in the lactation. Finally, the regression equation was applied to determine the proportion of total fat yield that was produced in the period from freshening to the end of the initial year. The same procedure was used for protein yield, except regression coefficients reflected smaller changes in protein percent during the lactation

Table 23. Coefficients of second order regression equations used to calculate the g parameter to account for effects of pregnancy in the milk yield equation, by lactation.

Lactation	Days in Milk	Intercept x 10^2	Days Open x 10^4	Days Open^2 x 10^6
1	< = 170	-.199	.1827	-.104
1	> 170	2.848	-2.872	.636
2	< = 170	-.2236	.2108	-.1303
2	> 170	4.02	-4.01	.8857
3	< = 130	-.2284	.2148	-.1359
3	131 to 169	-.1788	-.15	--[1]
3	> = 170	5.17	-5.00	1.07

[1] Only linear coefficient fit for this period on the deviation of days in milk from 131 to 169 d.

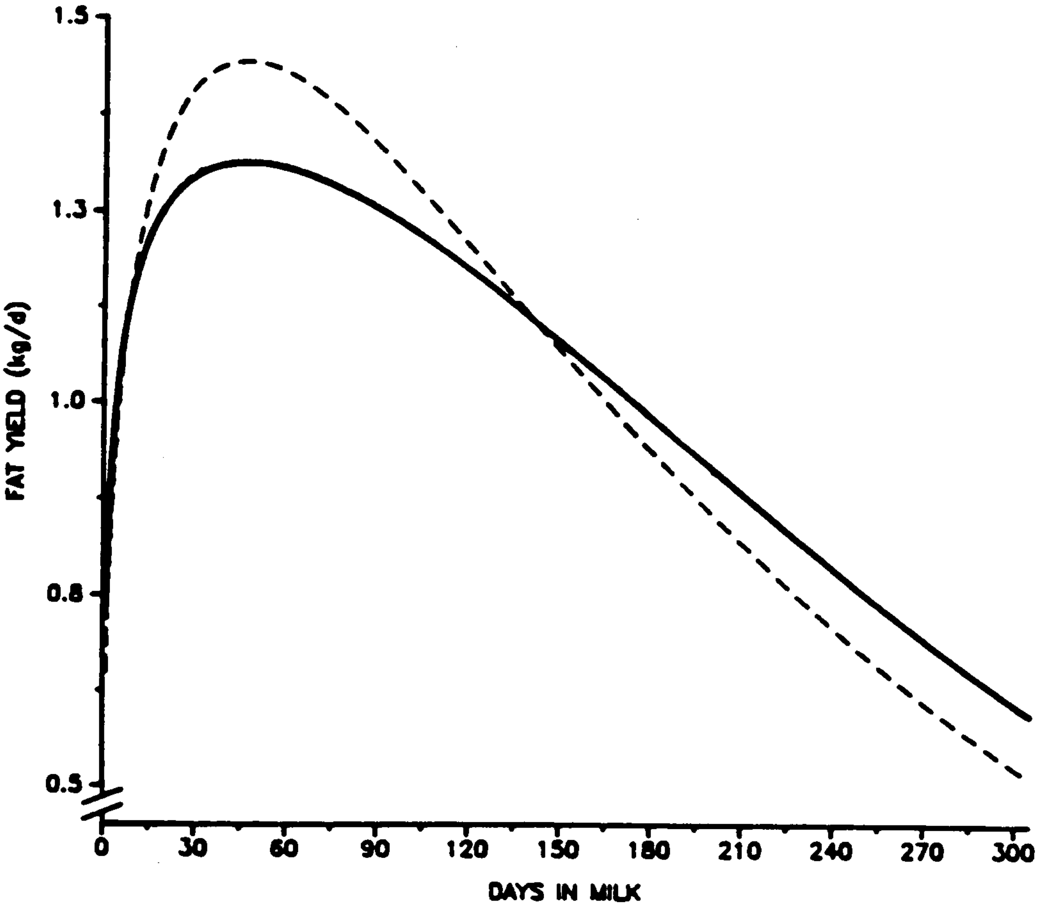

Figure 9. Fat yield curves using variable fat percent during lactation (solid line) and constant fat percent (dashed line).

than for fat percent. Table 24 lists coefficients for the second order regression equations used to estimate partial lactation fat and protein yield. Fat and protein yield were not calculated if the cow had less than 6 d in milk.

Calculation of mature equivalent milk, fat, and protein yield involves extension of records less than 305 d long to 305 d, and multiplying that yield by the mature equivalent correction factor to get mature equivalent yield. The same mature equivalent factors were used for milk, fat, and protein yield. If the cow was not pregnant, extension of the record used a most probable days open so not to overestimate yield by assuming she was open for 305 d. Most probable days open for cows less than 60 d in milk is 90 d, for cows greater than 60 d open and not pregnant the most probable days open is her days open plus 21 d, and for pregnant cows the most probable days open is the cow's actual days open. Because records are extended to 305 d, and a most probable days open is assumed for all cows, an effect of pregnancy is implied in estimated mature equivalent yield. Calculation of the effects of pregnancy on yield were described earlier. Since the extended record is 305 d, 305 d fat and protein yield are simply the extended milk yield times the average fat and protein percent. Mature equivalent milk, fat, and protein yield are calculated as the 305 d extended yield times the mature equivalent correction factor.

Final characteristics assigned to cows in the initial herds are scores for linear type traits, plus final score. Overall means for dairyness, stature, and udder depth are 27, 27, and 31 points from Foster et al. (30) using a 1 to 50 point scale. Actual scores for cows for these traits are deviations from the overall mean due to breeding value, permanent and temporary cow effects, and permanent and temporary herd effects. Scores are limited to the range of 1 to 50 points. Final score is predicted from the linear traits, with random error included. The linear scores are standardized by subtracting the mean from the cow's score and dividing by the SD for each trait. The SD for dairyness is 6.3, for

Table 24. Coefficients of second order equations used to determine cumulative fat and protein yield for cows in initial herds with partial lactations.

Lactation	Intercept	Days in Milk	Days In Milk^2 x 10^6
Fat Yield			
1	-.0096	.004	-2.2
2	-.0153	.0047	-4.4
3 to 10	-.0234	.0048	-4.7
Protein Yield			
1	-.01	.004	-2.4
2	-.016	.0048	-4.9
3 to 10	-.0254	.005	-5.3

stature is 5.4, and for udder depth is 6.5. These standardized scores are weighted for their importance in predicting final score, as stature is more important in predicting final score in Holsteins. The equation used to predict final score is:

$$S = 80 + .7(4\ \text{Stat} + 2\ \text{Dair} + 1.5\ \text{Udd}) + .3(2.08D)$$

where

S = the cow's final score

Stat, Dair, Udd = standardized scores for stature, dairyness, and udder depth

D = a Standard Normal deviate

The average score for all cows is 80 points, and coefficients for the standardized traits of 4, 2, and 1.5 represent weighting factors for the linear traits. Weighting factors and coefficients used to partition differences in final score between linear traits and random error were arbitrarily chosen to assign final scores that appear reasonable. Mean final score is limited to the range of 50 to 97 points.

Moving Cows and Herds Through Time

The experimental design of this study called for moving 20 herds of 80 cows each plus youngstock through 20 yr of simulated time. Herd parameters, such as permanent herd effects, number of cows, and random numbers needed to create correlated yearly effects, are passed from one year to the next for continuity of the simulation. This section describes biological relationships of cows as they are moved through time.

At the beginning of each herd and year, temporary herd effects for the seven transmitted traits are set for that herd-year. All cows calving in the herd during the current calendar year are assigned the same temporary effects for these traits. It was noted earlier that these effects were correlated across years within herd. This is done by storing the random deviates used to create temporary effects in the initial year, and then using the deviates when creating a new set of correlated deviates for the first year of the simulation. These new deviates are then stored for use in the next simulated year. The correlation used between years for all seven traits was .2. Including this correlation makes smaller the yearly differences within herd, and thus the herd changes less from one year to the next than if changes were uncorrelated. The expected mean for the temporary herd effects would still be zero.

An additional correlation between years is implied by assigning the same temporary herd effect to all cows fresh in the same calendar year. In this simulation, records on cows do not end at the end of a year, but lactations span across years depending on when the cow was fresh and the length of the lactation. At the beginning of a year, most cows would have temporary herd effects assigned from calving the previous year. All cows calving in the new year would be assigned new temporary herd effects, and as months progress into the new year the average temporary effect in the herd would gradually change.

After yearly effects are assigned, any heifers due to freshen in the next month are moved to the cow file. Heifers are still fed a heifer ration until they calve, at which time they are assigned characteristics of their first lactation. At first freshening a permanent record is written for the heifer, specifying her age at first calving and total rearing cost to calving. Records first updated within herd, year, and month are cow records, their milk yield, feed costs, income, and the creation of new calves. The calf file is updated after all cows are updated. By placing heifers ready to freshen in the cow file, all lactating animals can be updated with one pass through the data, and then all calves can be updated similarly.

The simulation was designed to read each herd, and then process all cows and calves in the herd monthly. Updating variables on cows and calves on a daily basis was too time consuming to be computationally feasible, so animals were updated in periods. The period length could be set by the program operator, and in this simulation was 10 d for cows and 14 d for calves. Characteristics that changed daily, like milk yield and body weight, were updated by predicting the daily value for the midpoint of the period, and multiplying that value by the period length. Since the number of days in each month is variable, and are not always multiples of 10 and 14, the period length was variable to account for differing number of days in the last period of each month. Cows and calves were updated by reading current information on each animal, passing that animal through the entire month, accumulating milk yield, feed costs, dry matter intake, and income, and then proceeding to the next animal. After all cows and calves are processed for a month, monthly net income records are written, voluntary culling is performed if herd size is too large or too many heifers are due to calve, and the cycle is started for the next month by moving heifers ready to calve to the cow file. At the end of each year, cow, calf, and herd files are permanently written to disk and used to start the next year.

At the beginning of each month it is determined for each cow if events such as freshening, drying off, estrus, or involuntary culling are due to occur in the month. If an event is to occur, its date is set. Cows are moved through the month in periods of 10 d until an event occurs or the month ends. When an event occurs, necessary updates to the cow's record are performed depending on the event. If the animal being updated is a heifer or is dry, feed intake, growth, feed and fixed costs, age, and days pregnant are updated until the animal is fresh. When an animal calves, milk yield, body weight change, age, and days in milk are updated. When the cow becomes pregnant, days pregnant are also updated. Feed intake is determined by milk yield, body size, and stage of lactation. Milk yield changes according to days in milk, pregnancy status, and occurrence of mastitis during the lactation until the cow goes dry or is culled.

Calves are updated similarly, except they do not yield milk. For heifers live at birth, age, growth, feed intake, and expenses are accumulated through weaning and breeding.

Once the heifer is pregnant, days pregnant are also updated until the animal is within one month of freshening, when she is transferred to the cow herd. Variables on calves are updated until first calving, or until they are culled involuntarily for death or infertility, or voluntarily as excess pregnant heifers.

A cow's breeding value is constant during her lifetime, as are the cow's permanent herd and permanent cow effects. Temporary herd and cow effects are carried over from the initial herd, and change at each subsequent freshening. Deviations from these effects are made for specific environmental occurrences. Assignment of permanent and temporary herd and cow effects were described in the initial herds. Milk yield is updated differently in this part of the simulation, as it is updated in 10 d increments rather than integrated to the end of the year.

Many of the characteristics associated with events during the cow's lactation are assigned at freshening to simplify the simulation model. The events do not necessarily occur at calving, however. At calving, if the animal is a first calf heifer, a permanent record of heifer characteristics is written. For cows, a completed milk yield record is written for the previous lactation. Completed lactation records are written at freshening so the days dry preceeding the calving may be stored in the current lactation. An alternative method would have been to end the record when the cow went dry. By writing the record at calving, days dry could be stored in the current lactation so adjustments to milk yield could be made for previous days dry. The cow's previous days open are also stored in the current record, and adjustments to milk yield for previous days open are also included. When the cow freshens, all lactation counters such as days in milk, days pregnant, days open, and lactation variables of milk yield, income, and expense are set to zero, and a new lactation is initiated.

Temporary herd and temporary cow effects, as well as mature equivalent correction factors, were assigned at freshening as previously described. Temporary herd effects were correlated across years, while temporary cow effects were uncorrelated. Base levels of the A, b, and c coefficients used in the Incomplete Gamma function to predict daily milk yield were assigned by lactation number and month fresh. Mature equivalent correction factors are listed in Table 19. Characteristics of the cow's calf are assigned next, as some of this information is necessary to predict dystocia. The calf's identification, dam, sire, maternal grandsire, and date of birth are determined, as well as gender from a random deviate, with 50% of all calves as heifers. Occurrence of twins was not simulated, however. Probability of reproductive problems included problems associated with twin births even though only single births were recorded.

After sex of the calf was determined, the occurrence of dystocia and subsequent birth weight of calves could be estimated. Probability of dystocia was adapted from Van Vleck and Edlin (90). In first calf heifers dystocia frequency was 9%, with 13% dystocia associated with a bull calf and 6% dystocia associated with a heifer calf. Frequency of dystocia in cows after first lactation was 3%, with bull calves generating 4% dystocia, and heifers 2%. Bull ratings for percent difficult births in heifers were 9 ± 2%. The probability of occurrence of dystocia in first calf heifers is the mean probability of dystocia depending on sex of the calf, plus the bull's percent difficult births in heifers deviated from 9%. For example, if a bull calf is born to a first calf heifer, and the sire of the calf has expected percent difficult births of 11%, then the probability of dystocia is 13% + (11%-9%), or 15%. A Uniform deviate is selected and compared with this value and if the deviate is less than or equal to the probability of dystocia, a case of dystocia is assumed. Thus, dystocia is a binomial trait in this simulation, either occuring or not. This may not be the best way to predict dystocia, assuming the underlying distribution of dystocia is continuous. However, when milk loss due to dystocia is predicted, a random deviate is applied to the milk loss to compensate for the discrete nature of dystocia. Frequency of dystocia is less and less variable in lactations two through ten for two reasons. First, the frequency of dystocia is lower, as stated above. Second, there is less variability in dystocia due to bulls used. This is because the values for expected percent difficult births is for heifers, and a bull with an 11% rating for expected percent difficult births when bred to heifers will have 2% more dystocia problems, but a smaller proportion than 2% when bred to cows. Reduction in the variability of bulls for dystocia in cows was performed by deviating the bull's expected percent difficult births from 9%, and multiplying that value by a factor of 2/7, or .2857. These adjustments lower both the frequency and variation of dystocia in older cows.

There are several consequences of dystocia, both on the calf and cow. For the cow, a charge of $50 is incurred for each case of dystocia due to a visit and treatment by a veterinarian. Cows with dystocia are assumed to have reproductive problems, and will average 20 d longer to first heat than cows calving normally, from Oltenacu et al. (62). From the work of Djemali et al. (26), lost milk due to dystocia is 330 kg in lactation one, 275 kg in lactation two, and 455 kg in lactation three and greater. These values are mature equivalent. A SD of 50 kg was included in estimation of milk loss to make milk loss more continuous. From Philipsson (69), there was a 3.5% greater chance of culling at calving due to dystocia than for normal calvings. Ten percent of cows with dystocia were assumed to become permanently sterile (62). Finally, cows with dystocia that were fertile had a reduction of 10 ± 2% in conception rate (69). Fifty percent of cows with reproductive problems could recover to normal fertility after each heat cycle of the cow (62).

Consequences of dystocia on calves are higher birth weights and higher death rates at birth. Average birth weight of heifer calves without dystocia is 38.6 kg, and is 41.0 kg if dystocia occurred. Birth weight of bulls from normal calvings averages 40.0 kg, and 43.9 kg if dystocia occurred. This accounted for the difference in birth weight of calves which helps determine dystocia. All birth weights had a SD of 4.8 kg. Death rate at birth for heifer calves of first calf heifers is 2.3%, and of cows is 1.1%. Death rate for normal births of bull calves in first calf heifers is 3.5%, and in cows is 3.3%. Philipsson (68) reported death rate in female calves resulting from dystocia births was 19.3% for first calf heifers and 14.7% for cows, and for bull calves from first calf heifers was 24.4%, and from cows was 23.4%. These values were incorporated into the simulation. Bull calves that were born dead received no salvage value, and bull calves born alive received a salvage value of $100 and were removed from the simulation. In retrospect, it may have been more desirable to assign a salvage value of $75 or to assign salvage value according to birth weight. Because bulls with higher expected percent difficult births have more dystocia in their calves, the calves weigh more at birth on average. This difference is incorporated into growth rate of the calf also, with calves resulting from dystocia having faster growth rates, correlated to the bull's breeding value for stature.

It was assumed that 35.75% of all cows calving had reproductive problems at or soon after calving (62), which included dystocia problems. In options with random mating of bulls to heifers, expected occurrence of dystocia is 4.9%, and in options with selection against dystocia in heifers, the expected occurrence of dystocia is 3.9% across all ages. For all cows that did not have dystocia at calving, the probability of other reproductive problems was assigned at random as 35.75% minus the expected probability of dystocia, with older cows having slightly more reproductive problems. More reproductive problems in older cows is estimated by adding the value

(Lactation-1) $(.15^{Lactation})$ to the probability of reproductive problems. This adjustment always causes a difference of less than 2% in the probability of reproductive problems, and was incorporated from Oltenacu et al. (62).

Cows in all lactations have their milk yield adjusted for days open in the current lactation through adjustment of the g parameter of the Incomplete Gamma function. For all cows after first lactation, adjustments are made for previous days dry and previous days open. First calf heifers had neither previous days open nor previous days dry. The adjustments are on a mature equivalent milk yield basis, and deductions (or additions) are included in the total expected milk yield for the current lactation at calving. Total expected milk yield was the sum of breeding value and all environmental effects. The adjustment implies that any deduction or addition of milk yield to the lactation due to previous days dry or previous days open was evenly distributed over the lactation. Effects of days open and days dry in the previous lactation on milk yield were derived from Funk et al. (34). These effects are deviated from average days open and average days dry, so positive as well as negative adjustments are possible. The data of Funk were fit to regression equations to make corrections more simplistic. The equation used to correct yield for previous days open was $Y = -465.6 + 3.903D - .00521D^2$, where Y is the additive correction to ME 3.7% FCM yield, in kg, and D is the number of days open in the previous lactation. A plot of this equation, and data from which it was estimated, are in Figure 10. Data for correcting days dry was more difficult to fit to a curve, so two equations were fit for the adjustment, depending on the number of days dry. If previous days dry were less than or equal to 65 d, the equation is $Y = -1357.7 + 44.395D - .2876D^2$, and if previous days dry is greater than 65 d, then the equation is $Y = 872.42 - 12.396D + .0535D^2$, where Y is the ME 3.7% FCM yield adjustment, and D is the previous days dry. Previous days dry was not allowed to exceed 125 d, as prediction of adjustments was unreliable for values higher than 125 d. A plot of these equations, and the data to which they were fit, is in Figure 11.

Involuntary culling of cows is determined at calving for the entire lactation for all effects except culling due to mastitis. Model options specified whether total involuntary culling was 12% or 24%. Forty percent of the total involuntary culls are for reproductive purposes, which included culling due to dystocia or other reproductive problems. There are 35.75% total reproductive problems in cows (62), including dystocia, and 10%

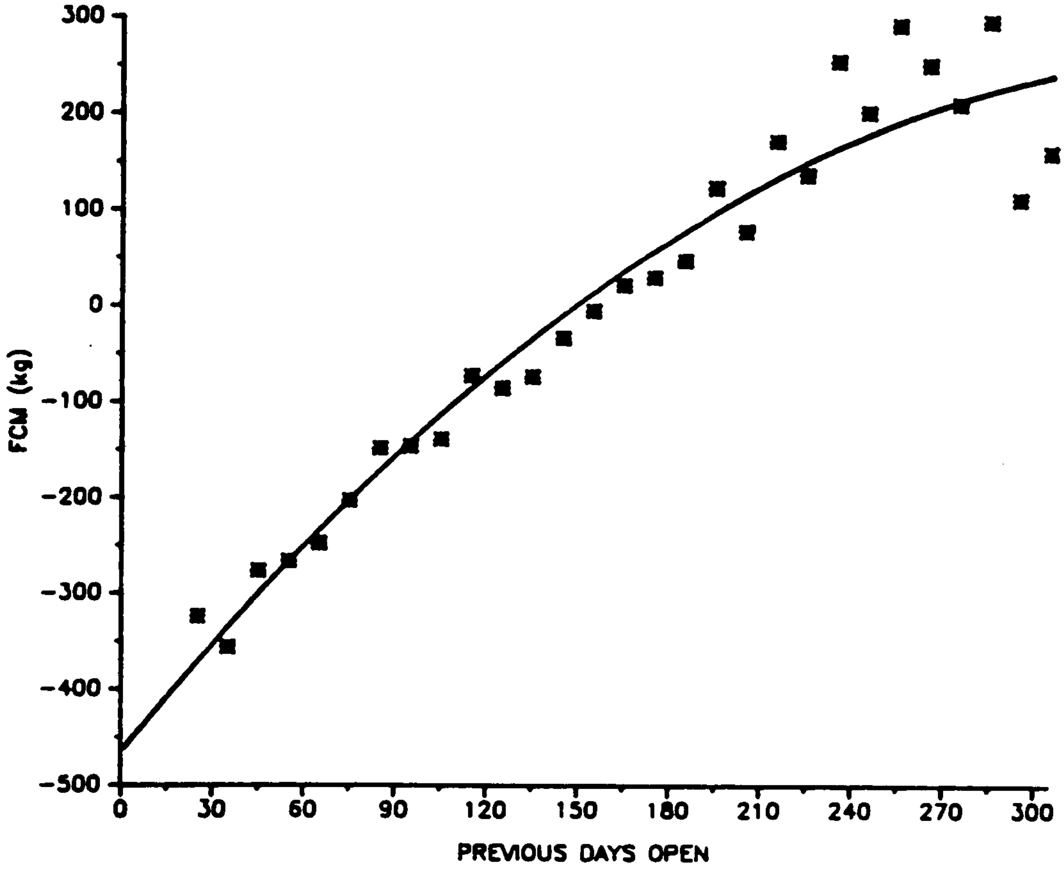

Figure 10. Plot of ME 3.7% FCM yield in the current lactation on previous days open, from data of Funk et al. (34).

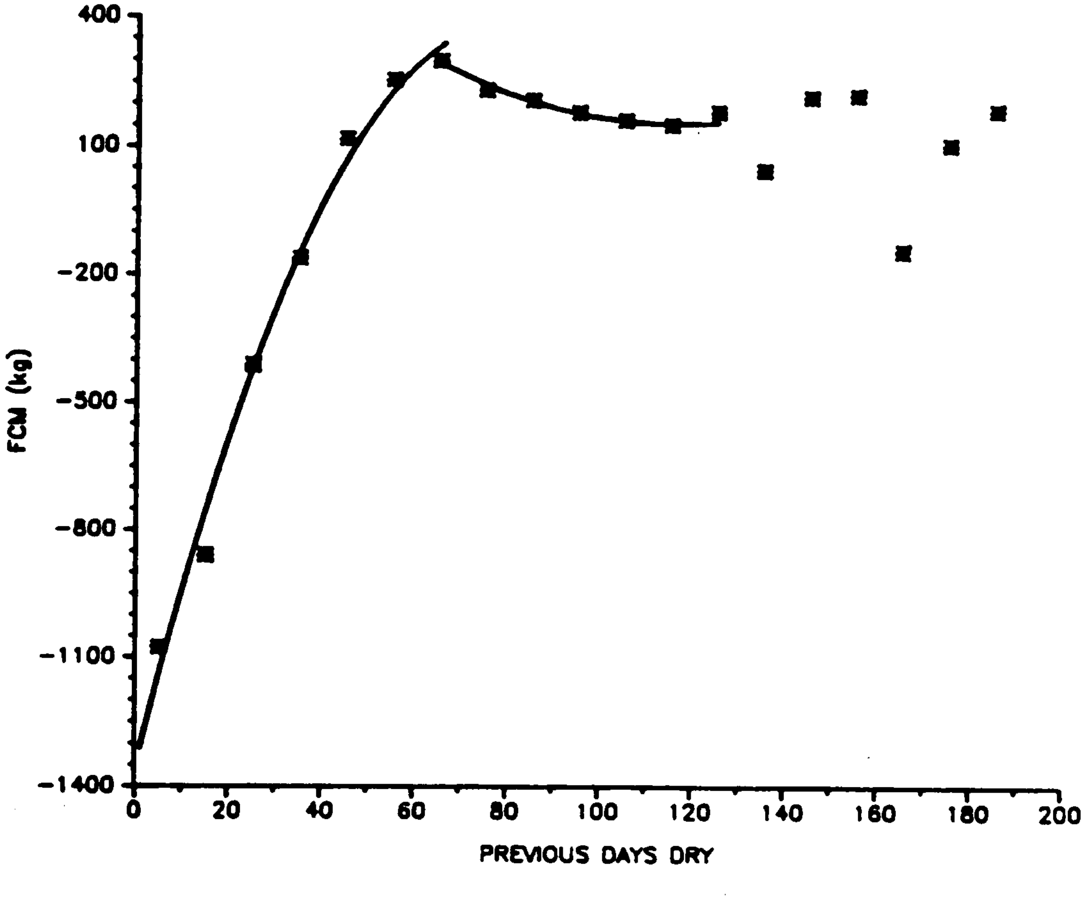

Figure 11. Plot of ME 3.7% FCM yield in the current lactation on previous days dry, from data of Funk et al. (34).

of these cows become permanently sterile and are considered non-breeders. Other reproductive culling accounts for the difference in culls from reproductive problems and the total culls needed. By specifying a maximum days open of 340 d, a specified number of fertile cows are culled before they become pregnant. Percent of total involuntary culls due to mastitis is 20%, percent due to disease is 24%, and percent died is 16%. For cows that die, 75% are assumed dead as a consequence of calving, and are removed from the herd at calving. Twenty-five percent of the deaths are distributed uniformly over the first 250 d of lactation.

Cows that die are charged $25 for labor or veterinary care and received no salvage value. Cows removed as a result of disease are removed uniformly over the first 250 d in lactation, and when removed are allocated a salvage value equal to their current body weight times 75% of the current monthly beef price. This implies that sick or diseased cows are not as valuable as healthy cows. No adjustments to the weight of these cows are made due to disease, so the reduction in value is through a lower beef price. Beef prices by month are from (52), averaged over the years 1985 to 1987, and are listed in Table 25. Most cows culled for reproduction are sterile, or fertile but not pregnant. They are allowed to remain in the herd and be bred, but sterile cows cannot become pregnant. These cows remain in the herd until they are culled for low net income, are culled for other involuntary reasons, or reach 340 d in milk and are not pregnant. Salvage value for reproductive culls is body weight times the current monthly beef price listed in Table 25. It is possible for cows designated as involuntary culls for one reason to be culled for another reason, or to be culled voluntarily for low net income, which would cause actual culling percentages to deviate from their expected values.

Occurrence of mastitis and involuntary culling due to mastitis are handled separately from other involuntary culling. Occurrence of mastitis is predicted from work of Morse et al. (54). Conditional probabilities of occurrence of mastitis are summarized in

Table 25. Monthly prices received for milk and beef, obtained from Miller et al. (52).

Month	Milk Price ($/kg)	Beef Price ($/kg)
January	.291	.836
February	.287	.902
March	.279	.927
April	.273	.900
May	.268	.913
June	.264	.903
July	.265	.882
August	.269	.881
September	.278	.897
October	.284	.869
November	.286	.846
December	.284	.853

Table 26. When a cow freshens, a random deviate is called and compared with the value in Table 26 for the first case of mastitis for a cow in a given lactation. This determines whether mastitis will occur in this lactation, since if a first case does not occur, then later cases cannot occur. If a cow contracts mastitis, then the time to her first case is predicted. First lactation cows have a higher proportion of their first cases before 35 d in milk (60%) than cows in fifth lactation and later (28%). Cases occurring before 35 d are uniformly distributed over that period, and first cases occurring after 35 d are normally distributed with mean 75 d and SD 8 d. No effects of mastitis are evident until time of the first case. Milk is discarded for 2 d representing treatment time, plus an additional 2 to 5 d for witholding time, as indicated by Seymour et al. (72). The volume of discarded milk is recorded in the cow's record. Income is not received for discarded milk, and treatment cost for mastitis is $12 plus $1/d of witheld milk.

At the end of each case of mastitis, milk yield to the end of lactation is reduced by 2% to reflect incomplete recovery from mastitis. Currently, effects of mastitis in one lactation do not influence milk yield in later lactations. Involuntary culling for mastitis is evaluated each time a case occurs. The total number of expected mastitis cases per year in a herd of 80 cows is 73 cases, based on the probabilities specified in Table 26. In the low involuntary culling option, 2.6% of all cases of mastitis are assumed severe, and the cow is culled. This will underestimate mastitis culling slightly, since once a cow is culled she cannot have another case of mastitis, and thus fewer cases occur. With high involuntary culling, 5.2% of total mastitis cases are culled. If a cow is culled for mastitis, it is at the end of her case. Thus, discarded milk and costs due to mastitis can be accounted for. No additional charges are included at culling, and the cow is credited with salvage value equal to her body weight times 75% of the current beef price, assuming the cow is not in good health. If the cow is not culled for mastitis, prediction of the next case, and time to the next case if it occurs, is estimated using conditional probabilities

Table 26. Conditional probabilities of occurrence of mastitis, by lactation and number of case, adapted from Morse et al. (54).

Lactation	Mastitis Case				
	1	2	3	4	5
1	.35	.20[1]	.10	.10	.00
2	.42	.43	.23	.26	.15
3	.57	.47	.36	.33	.27
4	.65	.60	.40	.40	.27
5 to 10	.71	.69	.45	.47	.36

[1] The probability of a second case of mastitis in the first lactation is 20%, after a first case has occurred.

in Table 26. For cows with additional cases of mastitis, time to the next case of mastitis is 40 ± 8 d from the end of the previous case. Cows can have a maximum of 5 cases of mastitis in a lactation, and cannot have mastitis when dry. Oliver and Sordillo (61) presented a discussion of dry cow mastitis, which was not included in this simulation. Although mastitis incidence was predicted in this simulation, several improvements could be added in the future. These include the relationship of mastitis to SCC, predicting milk loss due to mastitis as in (40), relating milk yield in future lactations to current mastitis, and including mastitis in the dry period.

All cows are susceptible to common diseases that are not severe enough to cause involuntary culling. Common diseases are included because of their frequency of occurrence and perceived importance to health costs. Diseases considered in this study are ketosis, milk fever, left displaced abomasum, locomotive problems, and respiratory problems. Estimates of incidence of diseases are from Curtis et al. (20) and Erb and Grohn (28), with health costs for diseases from Bertrand et al. (8). Table 27 lists the diseases considered in this simulation, their rate of occurrence in first and later lactations, the time to occurrence, and the cost associated with occurrence of each disease. A cow can have only one disease in a lactation, and cows with reproductive problems at calving are three times more likely to have milk fever than cows without reproductive problems. A sequential decision is made to predict disease occurrence. First, a Uniform deviate is obtained and compared with the total probability of disease to predict whether any disease will occur in this lactation. If a disease does occur, then a specific disease is selected based the cumulative probability of all diseases, whether the heifer is first lactation, and whether any reproductive problems have occurred in this lactation. Because only single diseases occur in each lactation, probabilities of occurrence of diseases are assumed independent and are slightly higher than some values reported which account for relationships between diseases within the same lactation.

Table 27. Common diseases, with their probability of occurrence, time of occurrence, and cost.

Disease	First Lactation Frequency (%)	Later Lactation Frequency (%)	Time of Occurrence (d ±SD)	Cost ($)
Ketosis	6.0	6.0	30 ±6	17.00
Milk Fever	4.0	7.7	at calving	15.00
Left Displaced Abomasum	0.5	2.6	40 ±8	40.00
Locomotive	6.0	6.0	200 ±25	8.00
Respiratory	7.0	7.0	90 ±10	10.00

Creation of milk yield by assignment of permanent and temporary environmental effects plus breeding value, and converting these values to the A, b, and c parameters of the Incomplete Gamma function of Congleton (14) have been described previously. For this part of the simulation two additional aspects of milk yield apply. First, at each calving adjustments are added to account for deviations in yield due to dystocia, previous days in milk, and previous days dry. These deviations are incorporated into the A, b, and c parameters as they are created. Second is in the use of the Incomplete Gamma function to predict and sum daily milk yield rather than integrating the curve as done in the initial herds. This method is simpler than integration, but is computationally more intensive because more calculations are required. Daily yield can be predicted directly with the Incomplete Gamma function if the A, b, and c parameters are known along with the current days in milk.

When a cow contracts mastitis, her milk yield is not reduced directly. Milk yield remains the same as it would normally, but the amount of discarded milk is stored for later use. After the end of a mastitis case, milk yield is reduced 2% for the remainder of the lactation to reflect an incomplete recovery. Each case of mastitis is associated with an additional 2% reduction in yield. Discarded milk is not credited to income, but is included in total lactation yield. Cases of mastitis early in lactation will be penalized more because the 2% reduction in yield starts at the end of a case of mastitis, thus the effect of the reduction is over a longer period of time when compared with cases occurring later in lactation. Effects of mastitis are not passed from one lactation to the next. It may be possible to estimate an effect across lactations by changing the permanent cow effect for yield as a consequence of mastitis in future programs.

Milk yield is predicted on a daily basis at the midpoint of each period, and accumulated in 10 d increments. As stated earlier, fat and protein yield vary within the lactation and must be deviated within the lactation to attain realistic estimates of daily percent and yield. From data of Swisher (80), the linear regression of fat percent on milk yield was -.03694, and data from Spike and Freeman (74) identified similar differences in fat percent due to stage of lactation by fitting constants for stage of lactation. In this simulation, daily fat percent is used in the calculation of income from milk. Protein percent is not used in this simulation, but its calculation is similar. At calving, the cow's fat and protein percent are assigned as deviations from average percents (3.7% for fat, 3.1% for protein) due to breeding value and environmental effects. The equation used to adjust fat percent within lactation is $D = F - .03694(M - E) + C$, where D is the daily fat percent deviated from the cow's average fat percent for the current lactation (F), M is the current daily milk yield for the cow, E is the expected average daily milk yield estimated at calving, and C is a correction factor. C is .0002 if lactation equals one, and .0009 for lactations two to ten. The linear regression of fat percent on deviated yield of -.03694 %/kg was estimated from data of Swisher (80), using test day milk yield and fat percent data. Estimated daily milk yield is calculated at freshening by summing breeding value, environmental effects, and adjustments due to dystocia and previous reproductive performance, and dividing by 305 d. Daily milk is from the Incomplete Gamma function for the cow's current days in milk. The correction factor was added so that total fat yield using the deviated fat percents would equal total milk times average fat percent. The relationship between daily deviated fat percent, and average fat percent for a normal lactation, is in Figure 12.

Adjustment of protein percent within lactation is similar, but the adjustment is smaller. The equation used for adjustment of protein percent is $D = P - .0002(M - E) + C$, where D is the daily deviated protein percent, P is average protein percent for this lactation, M and E are as described previously, and C is 0 for lactation one, and .0005 for lactations two to ten. Yield of fat and protein are calculated as the product of daily milk times the daily fat and protein percent, multiplied by 10 d

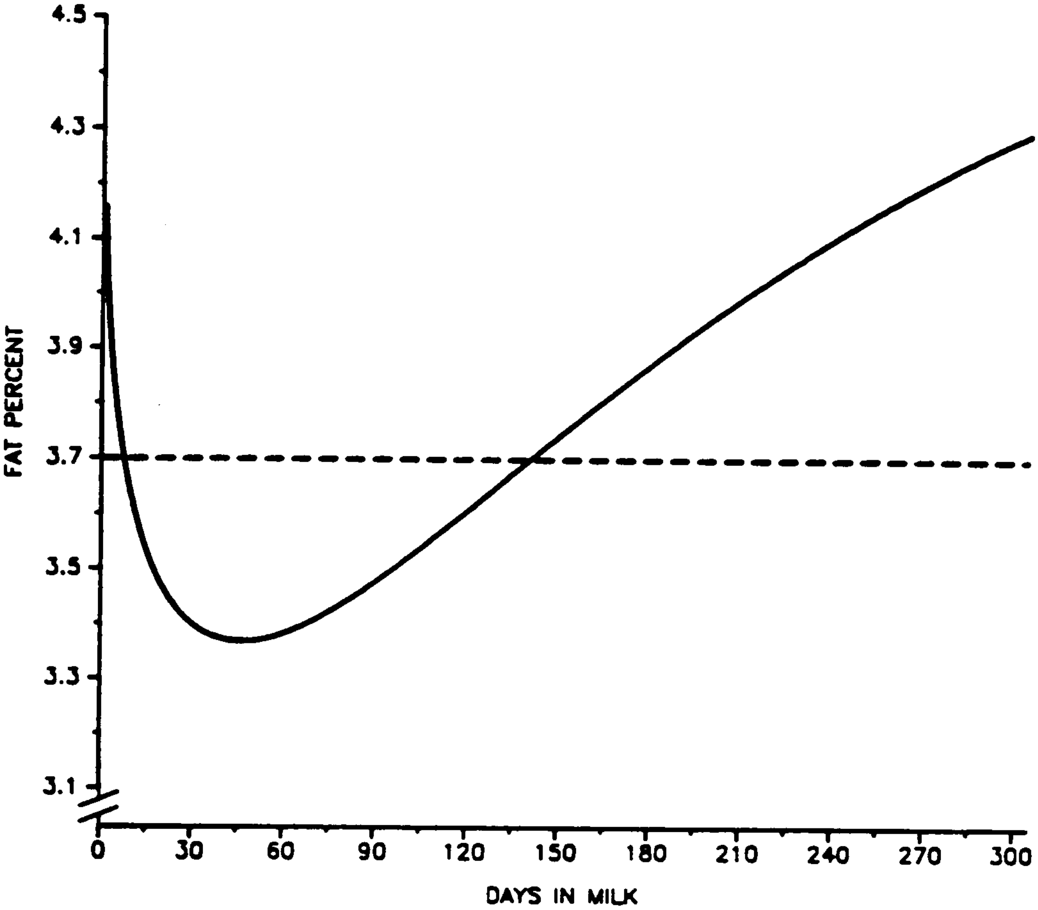

Figure 12. Plot of fat percent by days in milk deviated according to daily milk yield (solid line), and constant for the lactation (dashed line).

to accumulate yield over a period. Income due to milk yield is due to milk produced, current level of fat percent, and number of days in the period. Milk price differed by month, as listed in Table 25. Milk prices are 1985 to 1987 averages from (52). One value is used for fat differential, and is $.3733 per tenth of a percent deviation from 3.5%. For this simulation, prices for milk and beef vary by month of the year, but remain constant across years. Feed prices are also constant across years. This may be unrealistic, as Betts (9) noted the cost of producing milk rose 53% from 1975 to 1984. However, prices have not changed much since then, differences in prices over years are difficult to predict, and the ratio of prices received to the cost of inputs has remained relatively constant.

Cows are fed according to protein and net energy lactation requirements specified by the National Research Council (55). For each cow and in each period, daily requirements of protein and energy are estimated. These requirements vary by age, stage of lactation, milk yield, and reproductive status. When a cow is fresh, her days to peak milk yield are estimated as a ratio of Gamma parameters, b/c. Number of days to peak dry matter intake is 1.67 (b/c), ± 3 d. Since milk yield peaks at approximately 6 weeks into lactation, dry matter intake peaks at about week 10 of lactation, which is in agreement with work of Satter and Roffler (71) and Brown et al. (11). Individual cows can have peak yield and peak dry matter intake that are considerably different than 6 and 10 wk, depending on lactation number and milk yield relative to other cows in the herd. Cows can lose weight during this period if they need extra energy and have excess body reserves, up to 2 kg/d, down to 87% of their weight at calving. Cows cannot gain weight during the time between calving and peak dry matter intake. The equation was written in this form to force cows to lose weight, otherwise NRC requirements would simply assign the cow all the feed she needs, some of which she cannot consume. After peak dry matter intake, cows can gain weight up to their next weight at calving. A maximum value on weight for cows in each lactation is assigned to eliminate unreasonably large weights. Maximum weight for first lactation heifers is 560 kg, for second lactation is 610 kg, and for third and later lactations is 700 kg. Body weight change in cows in this simulation does not consider the weight of the calf and fluids related to the calf, as described by Korver et al. (41).

Cows producing high levels of milk require high quality feed in large amounts with high concentrations of protein and energy to maintain production. NRC equations assign protein and energy required, but do not consider different sources of them in rations supporting different levels of production. To estimate the cost of rations containing various levels of protein and energy, ten rations were formulated according to (75) using common feedstuffs and current prices listed in Table 28. These rations were formulated to meet nutrient requirements of the cows, but were not formulated as maximum profit rations, as described by Brown and Chandler (12). Ingredients were substituted into rations to balance rations for different levels of production expected in the simulation. This created a differential cost structure per kg of dry matter intake due to the different feeds in the rations. A regression equation was fit for cost per kg of dry matter on concentration of protein, energy, and their interaction to predict daily feed cost for individual cows, based on their requirements for protein and energy. The equation used to predict cost per kg of dry matter is $C = -.528 + 4.167P + .404E - 2.367PE$, where C is the ration cost per kg dry matter for a cow with requirement P for protein percent and E for net energy for lactation (Mcal/kg dry matter).

The equation above is used to estimate feed costs for all lactating cows. Dry cows are fed a single ration consisting of 12% crude protein and .57 Mcal/kg net energy. Heifers are fed individually from birth to weaning, with a constant feed cost of $1.55/d to account for cost of milk, milk replacer, and calf starter. Heifers in all options are raised identically from birth to 180 d of age. From 180 d to breeding, heifers in the option of 32 mo age at first calving have slower growth rates, but consume the same ration

Table 28. Feeds used in ration formulation for heifers older than 6 mo, dry cows, and lactating cows.

Feed	Cost ($/907 kg)	Cost ($/kg DM)
Corn Silage	30.00	.087
Alfalfa haylage	45.00	.142
Orchardgrass Hay	75.00	.095
High Moisture Corn	78.00	.119
Whole Cotton Seed	175.00	.210
Corn Gluten Meal	310.00	.376
Soybean Oil Meal	275.00	.341
Dicalcium Phosphate	324.00	.361
Limestone	45.00	.050
Trace Mineral Salt	800.00	.891

as other heifers. These heifers consume less dry matter to account for the slower growth rate. From weaning to 180 d, feed cost per kg dry matter is estimated as .263 - .0005476 (A - 56), where A is the age of the heifer in days. Thus, at 56 d of age, cost per kg dry matter was $.263, and becomes lower as heifers approach 180 d of age, assuming calf starter can be replaced by more inexpensive feed sources. Feed cost from 180 d to breeding for all heifers is $.139/kg dry matter, and for all heifers from breeding to first calving, $.11/kg dry matter. Nutrient requirements for heifers are assigned as in (55) based on requirements of net energy for gain in heifers. Growth of heifers in this simulation is determined mainly by the desired weight and age at first calving. Deviations from mean gain are correlated with the permanent herd effect for yield and sire breeding value for stature, plus random error.

For the heat and breeding routine, days to first heat are specified at calving. The breeding policy for lactating cows is not to breed any cow before 50 d in milk, and after 50 d in milk not to breed any cow until her daily milk yield in pounds is less than her current days in milk. Average heat detection in normal months is 50%, and in July and August, 45%. Conception rate at first service is 60%, at second service is 55% and at third and greater services is 50%. In hot months (July, August), conception rates by service are 10% lower than in normal months. Heifers have 5% greater heat detection and conception rate across all months and number of services, compared with cows. Heifers are not bred before they weigh 320 kg. Conception rate increases in heifers with breeding values above average within year, and is lower in heifers with poorer breeding values, in agreement with Hansen et al. (38). Conversely, cows with high production have lower conception rates, and cows with lower production have higher conception rates. This is supported by data of Badinga et al. (4) and Olds et al. (60), who reported positive relationships between increased milk yield and number of services per conception. For cows, conception rate decreases 1% for each 302 kg increase in ME lactation yield above average yield, as described by Erb et al. (29). This adjustment is within year, and accounts for increasing breeding values in cows within birth year by deviating yield from the expected average yield within year. Deviation in conception rate from average was not allowed to exceed 15% for cows. For heifers, the maximum adjustment in conception rate is 10%, and is assigned as a 1% increase in conception rate per 500 kg increase in breeding value for milk, deviated from the expected average breeding value of all heifers within each birth year.

The final updates in the monthly progression of cows through time is voluntary culling decisions for cows and heifers. Voluntary culling in cows is determined first. If more than 82 cows are currently in the herd, the herd is culled back to 80 cows. Heifers are culled by determining the expected number needed as herd replacements in the next 2 mo. This is always 4 animals in this simulation. If fewer than 80 cows are in the milking herd, no heifers are culled. If 80 cows or more are in the herd and the number of heifers due to freshen is more than 4, heifers are culled so only 4 are available. Cows are culled on an index of their cumulative net income per day for the current lactation. Only cows greater than 210 d in milk and still lactating are considered for culling so not to discriminate against early lactation or dry cows. Additionally, the index is expressed as a deviation within lactation one, two, and three or greater so equal comparisons can be made across lactations. In each month where voluntary culling is necessary, the 10 cows with lowest cumulative net income and meeting the requirements stated above are considered candidates for culling. Up to the required number of culls, open cows with the lowest values for deviated net income per day are culled first. If more culls are needed, pregnant cows with lowest deviated net income are culled. Not more than 10 cows can be culled in one month. Culling of heifers, if necessary, is on pedigree index, which is one-half of the sire's plus one-half of the dam's breeding values for milk yield. Heifers with the lowest indexes are culled from among all heifers due within the next 2 mo. A maximum of 10 heifers can be culled in one month. Pregnant heifers sold are assigned a salvage value equal to their accumulated expenses up to the point of their sale, making their net income zero. Salvage value for cows is their current body weight times their beef price.

Results and Discussion

Herd Study

Relationship of the three factors evaluated in the herd study with time to cumulative payoff was evaluated using two models. Both models included the 2^3 combinations of involuntary culling, heifer rearing, and sire dystocia, plus effects for birth year of animals within herd, and two way interactions of birth year with levels of involuntary culling, heifer rearing, and sire dystocia. An effect for herds was in both models, but in different forms. The first model considered the herd effect categorical and random, whereas the second model used the permanent herd effect for milk yield as a covariate. An initial goal was to identify the most desirable model, which will be emphasized in this objective, as well as later objectives.

Time to cumulative payoff was calculated within birth year of animals, and included all costs and returns of animals born in the given herd and year. Cows that made profit were required to offset their own expenses, plus expenses of heifers that were removed early through death or culling.

The model containing herds as categorical effects was selected as the more desirable model for two reasons. First, this model had a multiple squared correlation (R^2) of .73, which was higher than the model that included the covariate for herds ($R^2 = .60$). Second, when herds were considered categorical, the 2^3 combinations of involuntary culling, heifer rearing, and sire dystocia could be tested by the herd within three way combination of involuntary culling, heifer rearing, and sire dystocia. This test is more appropriate and conservative than testing these effects with the residual error term, which was necessary in the model using herds as a covariate. Statistical testing of factors will be emphasized in this model. The model containing the covariate for permanent herd milk is important in predicting response of dependent variables as level of herd yield changes, and regression coefficients from this model will be reported. Additionally, preliminary evaluation of both models found interactions of birth year with main effects to be non-significant ($P > .10$). Thus, these interactions were removed from these and subsequent statistical models.

Birth year, herds, and the main effect of heifer rearing had statistically significant ($P < .01$) associations with time to cumulative payoff. All other effects were non-significant ($P > .10$). Least squares means and SE for all combinations of involuntary culling, heifer rearing, and sire dystocia are in Table 29. The two levels of age at first calving differed by 6 mo (26 vs 32 mo), however, differences in the time to cumulative payoff between the levels was 15.4 mo. Heifers calving at 26 mo attained cumulative payoff in 54.6 mo, whereas heifers calving at 32 mo attained payoff in 70.0 mo. Average time to payoff of expenses was 60.0 mo. There appear to be two components involved in this relationship. First, a portion of the 15.4 difference in months to payoff can be attributed directly to the 6 mo difference in age at calving. Second, older heifers cost an additional S170 to raise to first calving (S1200 vs S1030), so they must also offset that extra rearing expense. All other conditions in the simulation were applied equally across both levels of heifer rearing, so that other factors should not have influenced this difference. There were no differences in culling rates for old versus young calving options, however culling was applied during each lactation, so younger calving options would have more involuntary culling because thay had more lactations to a given time. This could also affect the difference in time to payoff.

Because some herd-years did not have a time to cumulative payoff, comparisons of least squares means do not have equal numbers of observations, thus standard errors are not equal for the least squares means. The largest difference is for different levels

Table 29. Least squares (LS) means and SE for time to cumulative payoff, by all combinations of involuntary culling, heifer rearing, and sire dystocia.

Involuntary Culling[1]	Heifer Rearing[2]	Sire Dystocia[3]	Least Squares Mean (mo)[4]	SE
1			61.1	1.35
2			63.4	1.36
	1		54.6	1.23
	2		70.0	1.47
		1	62.0	1.35
		2	62.5	1.36
1	1		54.6	1.77
1	2		67.6	2.02
2	1		54.5	1.71
2	2		72.4	2.11
1		1	59.8	1.75
1		2	62.4	2.04
2		1	64.2	2.06
2		2	62.6	1.77
	1	1	54.1	1.72
	1	2	55.0	1.77
	2	1	69.9	2.09
	2	2	70.1	2.05
1	1	1	54.0	2.44
1	1	2	55.2	2.58
1	2	1	65.5	2.50
1	2	2	69.6	3.16
2	1	1	54.2	2.41
2	1	2	54.8	2.42
2	2	1	74.3	3.33
2	2	2	70.5	2.59

[1] Effect for involuntary culling: 1 = 12% total involuntary culling, 2 = 24% total involuntary culling.

[2] Effect for heifer rearing: 1 = 26 mo age at first calving, 2 = 32 mo age at first calving.

[3] Effect for sire dystocia: 1 = random mating, 2 = mating calving ease bulls to heifers.

[4] Least squares means differed for main effect of age at first calving ($P < .01$). All other effects not significantly different ($P > .10$).

of age at first calving, as the SE for 26 mo age at first calving is 1.23, and the SE for 32 mo age at first calving is 1.47. Up to year 89, each birth year of the simulation had 147 and 153 herd-years (out of a possible 160) which were approximately equally distributed across levels age at first calving. However, in year 89 there were 139 herd-years, and in year 90 there were 124 herd-years. Most of this reduction was in herd-years at 32 mo first calving without a time to payoff, which results in some inbalance, and thus higher SE for those years.

The combination of factors associated with earliest time to cumulative payoff (54.0 mo) was 26 mo age at first calving, 12% (low) involuntary culling, and random mating of bulls to heifers, and the combination with latest time to cumulative payoff (74.3 mo) was 32 mo age at first calving, high involuntary culling, and random mating. The 74.3 mo time to payoff was 4 mo higher than any other option. Most of this difference was due to differences in age at first calving, as main effects of involuntary culling and sire dystocia were not significantly associated with time to cumulative payoff ($P > .10$). Statistical significance is not as important in these analyses as in other types of evaluations because simulated characteristics can be generated in sufficient numbers to cause any difference to be significant. Comparison of the least squares means for the main effect of involuntary culling indicated that 12% involuntary culling was associated with 2.3 mo earlier payoff than 24% involuntary culling. Although not statistically different, there is a tendency for herds with low involuntary culling to reach cumulative payoff sooner, presumably because more voluntary culling can be done on low net income, leaving more profitable cows in the herds. Differences between levels of involuntary culling might have been larger if pregnant heifers could be sold at a profit. In this simulation, when pregnant heifers were sold they received credit equal to their accumulated expenses, thus there was no benefit to raising extra heifers. Because herds with low involuntary culling have the opportunity to sell either more cows or more heifers, any profit were made on them would decrease time to payoff in this option.

Sire selection against dystocia in heifers paid off .5 mo later than random mating. Although the effects of dystocia are important due to their effect on yield and reproductive performance, sire selection against dystocia had little impact on time to cumulative payoff in this study. This is because differences in expected percent difficult births is small between the options. In the random mating option, expected percent difficult births in heifers is 9%, and is about 6% when selection against dystocia is practiced in heifers. In addition, heifers have the most dystocia cases, but represent only about 30% of total cows in the herd. Dystocia had specific relationships with production, reproduction, and health costs in this simulation, but these relationships could not be differentiated across options because of small differences in the frequency of occurrence of dystocia across options. However, in this study dystocia represents the current status of calving ease evaluations in the AI sire population. Sires used for random mating had higher PD Dollars than calving ease sires ($164 vs $153) which could have contributed to the random mating option having a slightly lower time to payoff.

An implication that could limit these results with respect to dystocia is that in the selection option only calving ease bulls were used for matings, and in the random mating option, matings were made to a large group of bulls (20). However, on many farms only a single bull is used each year, particularly if a herd bull is used. Knowledge about the bull's rating for calving ease is often non-existent. If only one bull were used for all matings to heifers, and this bull had a high expected percent difficult births in heifers, effects due to dystocia within herd-years could be more dramatic. It appears that sire selection against dystocia in heifers, or the use of a large group of bulls when mating heifers are equally successful in avoidance of dystocia problems.

Although a measure of genetic merit of bulls was not included in the statistical model, bull merit was represented in the model by inclusion of birth year of the cows. This is because each simulated year used a new set of sires, with each group of sires improving 63 kg in breeding value for milk yield. Any association of time to cumulative payoff with birth year also implies an association with performance measures on bulls, inasmuch as the year to year differences are reflected in the sires used. No other yearly effects that could accumulate over time were included in the simulation model. Birth year of cows was significantly associated with time to cumulative payoff ($P < .01$), with later birth years of the simulation having the lowest time to cumulative payoff. Least squares means for time to cumulative payoff, by birth year of cows, are in Table 30. Mean time to cumulative payoff decreased 7.3 mo as birth year increased from 76 to 88, a reduction of .61 mo per birth year. Years 88 to 91 were not included in this value as fewer herd-years paid off after year 88, evidenced by the increased SE in later years. This was a result of fewer observations for time to payoff in the 32 mo age at first calving option, as mentioned earlier. For the later years, herd-years with the lowest time to cumulative payoff would be the first to appear in these averages, so estimates of time to payoff would be biased downward in these years. Additionally, birth years after 91 had very few or no observations for time to cumulative payoff, and were not included in the statistical model.

Assuming that differences in time to cumulative payoff due to birth year could be attributed to sire differences, one can predict changes in time to cumulative payoff associated with changes in PD Dollars of sires used across years. Linear regression analysis of PD Dollars on year for the 420 bulls used in the herd simulation indicated that PD Dollars increased $7.90/yr. Considering the reduction of .61 mo of cumulative payoff per birth year, then an increase of 10 PD Dollars was associated with a reduction of .77 mo to payoff. Reduction in time to payoff as birth year increased was consistent,

Table 30. **Least squares (LS) means and SE for time to cumulative payoff, by year of birth.**

Year[1]	Least Squares Mean (mo)[2]	SE
76	67.6	.69
77	67.6	.69
78	64.6	.69
79	66.0	.70
80	63.8	.69
81	63.2	.68
82	63.4	.69
83	62.3	.69
84	62.1	.69
85	61.6	.69
86	59.6	.68
87	59.7	.69
88	60.3	.70
89	59.0	.72
90	57.6	.76
91	57.9	.92

[1] Simulated years were 76 to 94. Heifers born after year 91 did not have enough simulated time to attain cumulative payoff.

[2] Least squares mean differed for years ($P < .01$).

and relatively large. This is due mainly to improvement in the average breeding value of bulls each year, and the fact that bulls were only used in a single year. Thus, bull use did not overlap in different years, which should make year to year differences in time to cumulative payoff easier to identify. Birth year will be confounded with other yearly effects, if these effects exist.

Evaluation of model [1] substituting the effect of permanent herd milk yield as a covariate for herds was used for the purpose of evaluating the relationship of herd milk yield with time to cumulative payoff. The earlier model identified that herds differed in time to cumulative payoff, but no further information was available. The overall linear regression of time to cumulative payoff on permanent herd milk yield was -.015, indicating that each 100 kg increase in permanent herd milk was associated with 1.5 mo earlier payoff. Mean (± SD) permanent herd milk for these herds was 329 kg (± 769 kg). Thus, as permanent herd milk increased from minus one SD (-440 kg) to plus one SD (1098 kg), time to cumulative payoff decreased 23.1 mo, from 78.6 to 55.5 mo.

The interaction of permanent herd milk with age at first calving was significant ($P < .01$) for time to cumulative payoff, but interactions of permanent herd milk with involuntary culling and sire dystocia were not significant ($P > .10$). Linear regression coefficients for permanent herd milk on time to cumulative payoff were -.0156 at 32 mo age at first calving, and -.0116 at 26 mo age at first calving. As permanent herd milk increased 100 kg, herd-years with 26 mo age at first calving reduced time to payoff 1.16 mo, while herd-years with 32 mo age at first calving reduced time to payoff 1.56 mo. Between herds, increasing permanent herd milk was more important in herds with high age at first calving, where expenses of rearing heifers were higher and must be accounted for.

In this study, permanent herd milk remained constant over time. Herds with higher milk production, as measured by the permanent herd effect, require less time to cumulative payoff. It seems reasonable to expand this concept to any management alternative that increases production. Increasing herd production, even if not permanent, should reduce time to cumulative payoff if cost of the management intervention is within reason.

For the herd study, two estimates of profit per animal day to 96 mo were evaluated using the model described for objective 1. One estimate included a salvage value of $800 for each cow still in the herd at 96 mo. The other estimate did not include this salvage value. The $800 was chosen to represent the cow's salvage value for beef, plus an amount reflecting her continued usefulness as a dairy cow. Results from the models will emphasize profit per animal day, including salvage value of cows that remain in the herd at 96 mo. Because profit is calculated to a fixed point in time, animals remaining in the herd are discriminated against with respect to profit if they are not credited with salvage value. Because the difference in rank of options does not change when salvage value is removed, it can be concluded that the number of animals alive at 96 mo was not different among options.

The model evaluating profit per animal day with salvage value, and treating herds as fixed effects, had an R^2 of .81. Main effects for age at first calving and involuntary culling were significantly associated with profit per animal day ($P < .02$), as were birth year and herds. These same effects were significant in the model predicting profit per animal day without salvage value for animals surviving 96 mo, but this model had a slightly higher R^2 (.84). Least squares means for all 2^3 combinations of involuntary culling, heifer rearing, and sire dystocia are in Table 31.

Overall profit per animal day to 96 mo, including salvage value of surviving cows, was $.36. The system resulting in the highest profit per animal day was 12% involuntary culling, 26 mo age at first calving, and random mating ($.485/d), while the system resulting in the lowest profit per animal day was 24% involuntary culling, 32 mo age at

Table 31. Least squares (LS) means and SE for profit per animal day, with and without salvage value, by all combinations of involuntary culling, heifer rearing, and sire dystocia.

			With Salvage Value[1]		Without Salvage Value	
Involuntary Culling[2]	Heifer Rearing[3]	Sire Dystocia[4]	LS Means[5] ($)	SE	LS Means[5] ($)	SE
1			.399	.023	.332	.023
2			.318	.024	.261	.024
	1		.432	.024	.374	.024
	2		.285	.024	.219	.024
		1	.364	.024	.302	.024
		2	.353	.024	.292	.024
1	1		.474	.033	.411	.033
1	2		.323	.032	.253	.032
2	1		.391	.033	.337	.033
2	2		.246	.033	.185	.033
1		1	.404	.033	.338	.033
1		2	.393	.033	.327	.033
2		1	.324	.033	.266	.033
2		2	.313	.033	.257	.033
	1	1	.444	.033	.386	.033
	1	2	.421	.033	.363	.033
	2	1	.284	.033	.218	.033
	2	2	.285	.033	.221	.033
1	1	1	.485	.046	.422	.046
1	1	2	.464	.046	.401	.046
1	2	1	.322	.045	.253	.046
1	2	2	.323	.046	.253	.046
2	1	1	.403	.047	.349	.047
2	1	2	.378	.046	.326	.046
2	2	1	.246	.046	.182	.046
2	2	2	.247	.046	.188	.046

[1] Value for profit per animal day included a salvage value of $800 for all animals still in the herd at 96 mo.

[2] Effect for involuntary culling: 1 = 12% total involuntary culling, 2 = 24% total involuntary culling.

[3] Effect for heifer rearing: 1 = 26 mo age at first calving, 2 = 32 mo age at first calving.

[4] Effect for sire dystocia: 1 = random mating, 2 = mating calving ease bulls to heifers.

[5] LS means differed for main effects of age at first calving and involuntary culling ($P < .01$). All other effects not significantly different ($P > .10$).

first calving, and random mating (\$.246/d). Age at first calving and level of involuntary culling both contributed to differences in profit per animal day, whereas sire dystocia did not. Reasons for the non-significance of sire dystocia were the same as for objective 1. Decreasing age at first calving from 32 to 26 mo increased profit per animal day \$.147, from \$.285 to \$.432. Decreasing involuntary culling from 24 to 12% increased profit per animal day \$.081, from \$.318 to \$.399. Inclusion of salvage value for animals increased profit per animal day by an average of \$.064.

Reasons for the increase in profit per animal day as age at first calving decreased were the same as for objective 1. The profitability of low involuntary culling arises from more animals being culled voluntarily for low net income in the low involuntary culling option. Differences in time to payoff were not significantly different between levels of involuntary culling, whereas profit was different between levels of involuntary culling. It appears that involuntary culling did not influence time to payoff greatly, but more profit is made after the time to payoff is attained in the low involuntary culling option. This is because more cows can be culled for low net income in the low involuntary culling option. Apparently, the direct relationship of voluntary culling based on net income influenced the significance of the test in this objective, but with most of the effect realized after payoff was attained. Time to cumulative payoff, measured in objective 1, was not as directly related to voluntary culling as it represents a measurement at an earlier time. However, evidence suggests that the time to cumulative payoff and profit per animal day are similar measures of profitability, since herds that attained cumulative payoff earlier had more time to accumulate profit through 96 mo.

Table 32 lists least squares means for profit per animal day by birth year. Birth year was significant for profit per animal day ($P < .01$). Similar to cumulative payoff, herd years after year 88 did not have values for profit per animal day at 96 mo, because animals born later than year 88 did not have enough time to complete 96 mo of herdlife.

Profit per animal day increased from $.308 in year 76 to $.433 in year 87, for an increase of $.01 per birth year, or $.03 per 10 PD Dollars, using the same assumptions about sire progress as in objective 1. That increase of $.01 per animal day was the same when salvage value was not included for surviving cows, athough average profit was $.064 lower for cows without salvage value ($.36/d vs $.296/d). There was less data available for estimation of the least squares mean for year 88, plus the values reported would be the earliest completed lifetime to 96 mo. It is likely that the mean profit per animal day is lower in year 88 ($.321/d) because of the incomplete data.

The overall linear regression of profit per animal day on permanent herd milk yield was .00023 ($P < .01$), indicating that each 100 kg increase in permanent herd milk was associated with an increase of $.023/d at 96 mo. The regression was the same when salvage value for surviving cows was not considered. Significant interactions existed between permanent herd milk and age at first calving ($P < .01$), and between permanent herd milk and involuntary culling ($P < .06$). An increase in permanent herd milk of 1538 kg, representing the difference from minus one SD to plus one SD in permanent herd milk yield, resulted in a $.074 greater increase in profit per animal day for 26 mo age at first freshening than for 32 mo age. This implies that animals calving earlier return more money to the farm operation sooner, and thus differences in profit per day to 96 mo are compounded over time, especially for cows producing more milk. The interaction of permanent herd milk with involuntary culling was similar to the association of permanent herd milk with age at first calving, but smaller in magnitude. Increasing permanent herd milk 1538 kg resulted in $.021 more profit per day under 12% involuntary culling compared with 24% involuntary culling. In this case, compounding of profit appears to take place because of increased income due to more voluntary culling in the low involuntary culling option.

Table 32. Least squares (LS) means and SE for profit per animal day, with and without salvage value, by year of birth.

	With Salvage Value[1]		Without Salvage Value	
Year[2]	LS Mean[3] ($)	SE	LS Mean[3] ($)	SE
76	.308	.0089	.242	.0080
77	.322	.0088	.252	.0080
78	.342	.0088	.276	.0079
79	.325	.0089	.262	.0080
80	.348	.0088	.284	.0080
81	.351	.0089	.288	.0080
82	.371	.0088	.304	.0079
83	.376	.0088	.310	.0080
84	.373	.0088	.306	.0080
85	.382	.0088	.315	.0079
86	.410	.0089	.346	.0081
87	.433	.0088	.368	.0079
88	.321	.0173	.305	.0156

[1] LS means included an $800 salvage value for all cows surviving through 96 mo.

[2] Simulated years were 76 to 94. Heifers born after year 88 did not have enough simulated time to survive to 96 mo.

[3] LS means differed for years ($P < .01$).

The similarity in results of models evaluating profit per animal day at 96 mo with and without salvage value of surviving cows indicates these two estimates are similar measures of profitability. Differences between these two measures do not exist because herd size was held constant at 80 cows, and approximately the same number of cows survived to 96 mo of age in each option ($\bar{x} = 4.7$). The mean number of cows surviving at 96 mo across options ranged from 3.9 to 5.5 cows, plus the difference in salvage value of these cows is spread over all cows and over 96 mo. Also, because of the model factors related to profit per animal day and the magnitude of differences in profit per animal day associated with changes in these factors, profit per animal day seems to be a similar measure to time to cumulative payoff from objective 1. Since differences in the number of cows surviving to 96 mo is small across options, it is unlikely that the relationship of lifetime profit or profit per day with the options would be much different than profit at 96 mo.

The goal of objective 3 in the herd study was to determine whether the eight management combinations expressed their influence through milk yield/cow/yr and net income/cow/yr. Milk yield and net income were dependent variables, with the eight options independent variables along with herd and simulation year. Utilizing the model that considered herds as categorical effects, none of the eight combinations of involuntary culling, heifer rearing, and sire dystocia were significantly ($P > .10$) associated with either milk yield/cow/yr or net income/cow/yr. Herd and simulation year were significantly associated with both dependent variables ($P < .01$). The R^2 for both models, at .81 each, was high. Virtually all of the model variation was explained by differences among herds and years, however. This implies that milk yield/cow/yr and net income/cow/yr, and hence milk yield and net income, were not related to the eight options. This also implies that on a per cow per year basis, milk yield and net income are not the same measures as time to payoff or profit per day, as the latter variables were associated with the eight factors in previous models. Therefore, in models where milk yield or similar measures of performance are included as independent variables, part-whole correlations between milk yield, net income, and the eight options are probably unimportant.

Least squares means for milk yield/cow/yr and net income/cow/yr, listed by the eight options, are in Table 33. Ignoring the fact that there are not statistical differences in milk yield across the eight options, 12% involuntary culling was associated with 133kg more milk/cow/yr than 24% involuntary culling, 26 mo age at first calving had 51 kg more milk yield than 32 mo age at first calving, and random mating had 24 kg more milk yield than sire selection against dystocia. It seems reasonable that low involuntary culling should be associated with the largest difference in yield, as more voluntary culling could be performed on low net income, and hence production. Similar response was found for net income/cow/yr.

It is not surprising that significant relationships were not found between milk yield, net income, and the eight options. Production, reproduction, and reproductive health costs were different for cows with dystocia, but the difference in frequency of dystocia between the options was small. No direct relationships were programmed into the simulation between age at first calving and milk yield. Age at first calving was related to lifetime net income as younger calving heifers cost less to raise, but in this objective, net income/cow/yr was measured only for lactating and dry cows. Involuntary culling was associated with yield and net income inasmuch as differences in yield and income are changed by culling more cows voluntarily for low net income in the low involuntary culling options. Without large differences in the frequency of involuntary versus voluntary culling, and without large differences in yield of cows culled across options, these effects would be small also.

Table 33. Least squares (LS) means and SE for milk yield and net income, expressed on a per cow per year basis, by all combinations of involuntary culling, heifer rearing, and sire dystocia.

			Milk Yield/cow/yr[1]		Net Income/cow/yr[2]	
Involuntary Culling[3]	Heifer Rearing[4]	Sire Dystocia[5]	LS Mean (kg)	SE	LS Mean ($)	SE
1			6904	80.59	683.60	18.49
2			6771	80.59	657.89	18.49
	1		6863	80.59	681.51	18.49
	2		6812	80.59	659.98	18.49
		1	6849	80.59	674.41	18.49
		2	6825	80.59	667.08	18.49
1	1		6929	113.97	693.84	26.15
1	2		6879	113.79	673.36	26.15
2	1		6797	113.79	669.18	26.15
2	2		6745	113.79	646.60	26.15
1		1	6912	113.97	687.49	26.15
1		2	6896	113.97	679.71	26.15
2		1	6787	113.97	661.33	26.15
2		2	6755	113.97	654.45	26.15
	1	1	6895	113.97	688.49	26.15
	1	2	6831	113.97	674.53	26.15
	2	1	6804	113.97	660.33	26.15
	2	2	6820	113.97	659.63	26.15
1	1	1	6947	161.18	698.82	36.99
1	1	2	6911	161.18	688.86	36.99
1	2	1	6877	161.18	676.16	36.99
1	2	2	6882	161.18	670.56	36.99
2	1	1	6843	161.18	678.16	36.99
2	1	2	6751	161.18	660.19	36.99
2	2	1	6731	161.18	644.50	36.99
2	2	2	6759	161.18	648.70	36.99

[1] LS means for milk yield/cow/yr for all effects not significantly different (P > .10).

[2] LS means for net income/cow/yr for all effects not significantly different (P > .10).

[3] Effect for involuntary culling: 1 = 12% total involuntary culling, 2 = 24% total involuntary culling.

[4] Effect for heifer rearing: 1 = 26 mo age at first calving, 2 = 32 mo age at first calving.

[5] Effect for sire dystocia: 1 = random mating, 2 = mating calving ease bulls to heifers.

Table 34 lists least squares means for milk yield/cow/yr and net income/cow/yr by year of the simulation. Simulation year was significantly associated with milk yield and net income ($P < .01$). Milk yield/cow/yr improved 35 kg, which is slightly more than one-half of the improvement in sire breeding value per year (60 kg). Improvement in net income/cow/yr was $9.31. Improvement in milk yield/cow/yr seems within the range of reasonable values, however net income/cow/yr appears to be increasing at a faster rate than it should. Perhaps this is due to the fact that milk yield increased during the simulation, but fixed costs, cost of feed ingredients, and milk prices remained constant.

The linear regression of milk yield/cow/yr on permanent herd milk was .89. The regression is not 1.0 because the permanent herd effect is specified in mature equivalent milk yield, and milk/cow/yr is in actual yield. This means that an increase of 1 kg of mature equivalent permanent herd milk results in an increase of .89 kg actual yield/cow/yr. The ratio of 1/.89 (1.12), is close to the average mature equivalent correction factor for all cows in the herd. None of the interactions of permanent herd milk with involuntary culling, heifer rearing, and sire dystocia were significant ($P > .10$), although the interaction of permanent herd milk with involuntary culling approached significance ($P < .14$). This implies some confidence in the 130 kg difference observed between the levels of involuntary culling mentioned earlier. The linear regression of net income/cow/yr on permanent herd milk was .201. The magnitude of increase in milk yield/cow/yr of .89 kg, times the average milk price of $.29/kg, is valued at $.255. This indicated that .201/.255, or 79% of the increase in the value of milk produced went directly into net income. This value includes only values from the milking herd, and feed costs as the only expense increasing with production. Interactions of permanent herd milk with involuntary culling, heifer rearing, and sire dystocia were not significantly ($P > .10$) associated with milk/cow/yr or net income/cow/yr.

Table 34. Least squares (LS) means and SE for milk yield and net income, expressed on a per cow per year basis, by year of simulation.

	Milk Yield/cow/yr[1]		Net Income/cow/yr[2]	
Year[3]	LS Mean (kg)	SE	LS Mean ($)	SE
75	6636	30.58	596.31	6.80
76	6229	30.58	542.41	6.80
77	6335	30.58	574.32	6.80
78	6388	30.58	589.24	6.80
79	6524	30.58	617.14	6.80
80	6578	30.58	620.90	6.80
81	6704	30.58	656.59	6.80
82	6707	30.58	647.13	6.80
83	6824	30.58	671.91	6.80
84	6872	30.58	677.43	6.80
85	6916	30.58	682.34	6.80
86	6944	30.58	689.74	6.80
87	6931	30.58	687.23	6.80
88	7015	30.58	708.98	6.80
89	7069	30.58	718.03	6.80
90	7104	30.58	719.52	6.80
91	7182	30.58	738.06	6.80
92	7217	30.58	747.05	6.80
93	7275	30.58	757.43	6.80
94	7306	30.58	773.11	6.80

[1] LS means for milk yield/cow/yr differed by simulation year ($P < .01$).

[2] LS means for net income/cow/yr differed by simulation year ($P < .01$).

[3] Data collected in simulated years 75 to 94.

Evaluation of simulated DHIA variables investigated effects of the eight options on averages within herd and simulation year for age at first calving, days open, days dry, number of services per conception, days to first heat, and days to first breeding. Each model will be discussed individually. These models were used to evaluate the relationships between the dependent variables and the eight options, and also for validation of the simulation model by obtaining averages of response variables.

Mean age at first calving was 894 d, or 29.4 mo. The model evaluating age at first calving had an R^2 of .99, with virtually all of the variation in the model explained by the difference in levels of the main effect of heifer rearing (Table 35). Simulation year was significantly associated with age at first calving ($P < .01$), but trends in age at first calving over years were not evident, as seen in Table 36. In addition to simulation year and heifer rearing, other factors significantly associated with age at first calving were herds ($P < .01$), the main effect of involuntary culling ($P < .05$), and the three way interaction of involuntary culling, heifer rearing, and sire dystocia ($P \leq .10$). Some of these differences may be due to performing tests on factors with a small amount of variation after effects of heifer rearing have been accounted for. The variation left after heifer rearing had been accounted for may be too small to provide reliable statistical tests of significance. Level of involuntary culling should not have been related to age at first calving, because effects of involuntary culling were not scheduled to start until after the first calving.

The linear regression of age at first calving on permanent herd milk was significant ($P < .01$), as was the interaction of permanent herd milk with heifer rearing. This is likely due to the .3 correlation included between the permanent herd effect and heifer growth, which caused heifers to grow faster in higher milk herds, and thus breed and calve earlier, in agreement with Heinrichs and Hargrove (39). The regression coefficient of age at first calving on permanent herd milk was -.0031, indicating each 100 kg increase in permanent

Table 35. Least squares (LS) means (with SE) for simulated DHIA variables, by all combinations of involuntary culling, heifer rearing, and sire dystocia.

Independent Variable[1]			DHIA Variable[2]					
Icl	Hfr	Dys	Age (d)	Dopen (d)	Ddry (d)	Spc (#)	Dfh (d)	Dfb (d)
1			894 (.36)	136 (.44)	69 (.09)	1.63 (.01)	58 (.11)	113 (.24)
2			895 (.36)	136 (.44)	70 (.09)	1.63 (.01)	58 (.11)	113 (.24)
	1		801 (.36)	137 (.43)	70 (.09)	1.64 (.01)	58 (.11)	113 (.23)
	2		988 (.36)	135 (.45)	69 (.09)	1.62 (.01)	58 (.11)	113 (.24)
		1	894 (.36)	136 (.44)	69 (.09)	1.63 (.01)	58 (.11)	113 (.24)
		2	895 (.36)	136 (.44)	69 (.09)	1.63 (.01)	58 (.11)	113 (.24)
1	1		800 (.51)	137 (.59)	69 (.12)	1.64 (.01)	58 (.15)	113 (.32)
1	2		987 (.51)	136 (.61)	69 (.13)	1.63 (.01)	58 (.15)	113 (.33)
2	1		801 (.51)	137 (.59)	70 (.12)	1.64 (.01)	58 (.15)	113 (.32)
2	2		989 (.51)	135 (.61)	69 (.12)	1.62 (.01)	58 (.15)	112 (.33)
1		1	894 (.51)	137 (.60)	69 (.12)	1.63 (.01)	58 (.15)	114 (.33)
1		2	894 (.51)	136 (.60)	69 (.12)	1.63 (.01)	58 (.15)	113 (.33)
2		1	895 (.51)	136 (.60)	70 (.12)	1.63 (.01)	58 (.15)	113 (.33)
2		2	895 (.51)	136 (.60)	70 (.12)	1.63 (.01)	58 (.15)	113 (.33)
	1	1	801 (.51)	137 (.59)	70 (.12)	1.65 (.01)	58 (.15)	113 (.32)
	1	2	801 (.51)	136 (.59)	69 (.13)	1.64 (.01)	58 (.15)	113 (.32)
	2	1	988 (.51)	135 (.61)	69 (.12)	1.62 (.01)	58 (.15)	113 (.33)
	2	2	988 (.51)	135 (.61)	69 (.12)	1.63 (.01)	58 (.15)	113 (.33)
1	1	1	800 (.71)	138 (.83)	69 (.18)	1.65 (.01)	58 (.21)	114 (.45)
1	1	2	801 (.71)	136 (.83)	69 (.18)	1.63 (.01)	58 (.21)	113 (.46)
1	2	1	987 (.71)	136 (.84)	69 (.18)	1.62 (.01)	58 (.22)	113 (.46)
1	2	2	987 (.71)	136 (.84)	69 (.18)	1.63 (.01)	57 (.22)	113 (.46)
2	1	1	802 (.71)	136 (.83)	70 (.18)	1.64 (.01)	58 (.21)	113 (.45)
2	1	2	801 (.71)	137 (.83)	70 (.18)	1.64 (.01)	58 (.21)	113 (.45)
2	2	1	988 (.71)	136 (.85)	69 (.18)	1.62 (.01)	58 (.22)	112 (.46)
2	2	2	989 (.71)	135 (.84)	69 (.18)	1.62 (.01)	58 (.22)	112 (.46)

[1] Independent variables are: Icl is level of involuntary culling, Hfr is heifer rearing, and Dys is sire dystocia.

[2] DHIA variables are: Age is average age at first calving, Dopen is average days open, Ddry is average days dry, Spc is average services per conception, Dfh is average days to first heat, and Dfb is average days to first breeding.

Table 36. Least squares (LS) means (with SE) for simulated DHIA variables, by year of simulation.

Independent Variable[1]	DHIA Variable[2]					
Year	Age (d)	Dopen (d)	Ddry (d)	Spc (#)	Dfh (d)	Dfb (d)
77	884 (.82)	109 (1.83)	–[3]	1.17 (.04)	59 (.46)	105 (.99)
78	900 (.82)	120 (.71)	60 (.17)	1.47 (.01)	57 (.32)	105 (.42)
79	898 (.82)	136 (.71)	64 (.17)	1.67 (.01)	58 (.32)	111 (.42)
80	895 (.82)	136 (.71)	67 (.17)	1.67 (.01)	58 (.32)	112 (.42)
81	892 (.82)	138 (.71)	69 (.17)	1.67 (.01)	58 (.32)	113 (.42)
82	892 (.82)	138 (.71)	70 (.17)	1.65 (.01)	58 (.32)	114 (.42)
83	895 (.82)	139 (.71)	70 (.17)	1.67 (.01)	58 (.32)	114 (.42)
84	896 (.82)	139 (.71)	70 (.17)	1.68 (.01)	58 (.32)	114 (.42)
85	897 (.82)	140 (.71)	71 (.17)	1.68 (.01)	58 (.32)	114 (.42)
86	897 (.82)	139 (.71)	71 (.17)	1.68 (.01)	58 (.32)	114 (.42)
87	895 (.82)	140 (.71)	71 (.17)	1.69 (.01)	58 (.32)	115 (.42)
88	892 (.82)	139 (.71)	71 (.17)	1.67 (.01)	58 (.32)	114 (.42)
89	896 (.82)	139 (.71)	71 (.17)	1.66 (.01)	58 (.32)	114 (.42)
90	894 (.82)	139 (.71)	71 (.17)	1.66 (.01)	58 (.32)	114 (.42)
91	897 (.82)	140 (.71)	71 (.17)	1.69 (.01)	58 (.32)	115 (.42)
92	893 (.82)	140 (.71)	71 (.17)	1.67 (.01)	58 (.32)	115 (.42)
93	892 (.82)	139 (.71)	71 (.17)	1.65 (.01)	58 (.32)	115 (.42)
94	894 (.82)	140 (.71)	71 (.17)	1.67 (.01)	58 (.32)	115 (.42)

[1] Independent variable year is year of the simulation.

[2] DHIA variables are: Age is average age at first calving, Dopen is average days open, Ddry is average days dry, Spc is average services per conception, Dfh is average days to first heat, and Dfb is average days to first breeding.

[3] Least squares mean was not available for this year.

herd milk was associated with a .31 mo decrease in age at first calving. This decrease was faster in options with older age at first calving.

The model evaluating average days open identified simulation year, herd, and age at first calving as effects significantly related to average days open ($P \leq .01$). After the first two years of the simulation, differences between years for average days open were small (< 5 d). Average days open in the first year of the simulation was almost 30 d lower than in later years (Table 36). This could be attributed to a small number of animals with records in the early years. Overall average days open in the simulation was 137 d. Although age at first calving was significantly associated with the average number of days open, the difference in least squares means between the two levels of age at first calving was less than 2 d (Table 35). The R^2 for this model was .36, so less variation was explained in this model than models of previous objectives. Average days open had a regression coefficient of .0039 d/kg of permanent herd milk. This was a direct reflection of the breeding policy specified in the simulation program, which stated a cow could not be bred until her pounds of daily milk yield was greater than her days in milk. This forces high producers to be bred later and is a major contributor to high average days open in this simulation. This rule of thumb is currently used by some extension personnel. While there is some logic in breeding higher producing cows later, i.e., semen savings and increased milk in the current lactation, the choice of one day open per pound of milk may be too restrictive in high producing cows.

Average services per conception for cows in the milking herd was 1.65. Simulation year, herd, and age at first calving were significantly associated with the average number of services ($P < .05$). The R^2 for this model was low (.21), indicating most of the variation in services per conception was not attributed to factors in the model. The major difference in number of services was in the first 2 yr of the simulation (Table 35), after which number of services changed less than .02 over the remaining years. The permanent herd effect for milk was positively associated with number of services, but the magnitude of the regression coefficient was small (.0005 services/kg). Higher herd milk yield was associated with only slight increases in services per conception. This is a reflection of the simulation model, where lower conception rates were assigned to cows with high yield, which was derived from the permanent herd effect in addition to other effects of production.

Days dry in the simulation averaged 69 d. The R^2 for this model was relatively high at .69, and was influenced by simulation year, herd, age at first calving, and involuntary culling ($P < .01$). Although age at first calving and involuntary culling were significantly associated with average days dry, differences in days dry across levels of these variables were less than 1 d (Table 35). Average days dry was lowest in early years of the simulation, and averaged about 70 d from year 83 to 94 (Table 36). The fact that days dry, days open, and services per conception were all lower in early years of the simulation, as well as their having higher SE's, probably signifies that too few cows were available to get reliable estimates in the first few years. The positive linear regression coefficient of days dry on permanent herd milk (.0008 d/kg) is a result of high producing cows having greater days open, and thus higher days dry. The equation of Oltenacu et al. (63) was used to predict days open, and cows with longer days open also had longer days dry.

Average days to first heat was 58 d. Two gamma distributions were used to predict days to first heat, one for cows with normal calvings and the other for cows with reproductive problems at calving, which included dystocia. Because of small differences in frequency of occurrence of dystocia across options, significant differences were not observed for days to first heat between levels of dystocia. The R^2 for the model predicting days to first heat was .06, and none of the model factors, including simulation year and herd, were significantly related to days to first heat ($P > .05$).

The R^2 for average days to first breeding was .28, with simulation year and herd significantly associated with days to first breeding ($P < .01$). These can both be attributed to differences in production over years and across herds, as higher producers were automatically bred later because of decisions in the simulation model. Average days to first breeding were lower in the first two years of the simulation (Table 36), but still showed a steady increase over the remaining years, presumably as production increased. The positive regression of days to first breeding on permanent herd milk (.0022 d/kg) supports the relationship of higher production associated with higher days to first breeding. Once again, this can be explained by the breeding policy employed in this simulation not to breed cows before their milk yield in pounds was less than their days in milk.

Age at first calving was significantly associated with days to first breeding ($P < .07$). Age at first calving was significantly associated with several of the DHIA variables, or was approaching significance. It is possible that age at first calving was related to these measures because they represent similar measurements in many ways. If age at first calving was related to one DHIA variable, then it could be related to others although no specific relationships between them were included in the simulation model. Table 37 contains mean squares for herd within the three way interaction of involuntary culling, heifer rearing, and sire dystocia, plus residual mean squares for models evaluated in the herd study. Mean squares are necessary to determine sample sizes for future experiments. The R^2 for each of the models used in the herd study are also listed in Table 37.

Table 37. Mean squares of model effects for herd, used to test differences in model factors, residual error, used to test herd and year, and variation due to the statistical model (R^2).

Model[1]	Mean Square Herd	Mean Square Residual	R^2
Time to cumulative payoff	1719	70.23	.73
Profit/animal day to 96 mo	.5083	.010093	.84
Net cash income/cow/yr	547,280	7401	.81
Milk yield/cow/yr	10,392,858	149,621	.81
DHIA[2]			
Age at first calving	183.89	106.33	.99
Days open	231.88	79.86	.36
Days dry	10.60	4.63	.69
Services per conception	.0532	.0294	.21
Days to first heat	16.09	16.83	.06
Days to first breeding	73.92	28.89	.28

[1] Models listed contained effects for the 2^3 combinations of involuntary culling, heifer rearing, and sire dystocia, plus herds as categorical effects.

[2] DHIA variables evaluated in objective 4.

Cow Study

Objective 1 of the cow study evaluated differences among the eight options, cow merit for production, and sire merit for PD Dollars on time to cumulative payoff and time to cumulative profit of individual cows. Models evaluated contained the 2^3 combinations of involuntary culling, heifer rearing, and sire dystocia, the 2^3 combination of factors plus cow merit, and the 2^3 combination of factors plus sire PD Dollars. The model selected as most desirable contained main effects and interactions of involuntary culling, heifer rearing, and sire dystocia, the covariate for cow merit for milk yield, and two way interactions of cow merit with the main effects. This model, evaluating all cows with a time to cumulative payoff, had an R^2 of .45, whereas the model evaluating time to cumulative payoff with PD Dollars as a covariate had an R^2 of .31, and the model without either covariate also had an R^2 of .31. All three models yielded almost identical least squares means.

In addition to selecting the most desirable model, these models were also evaluated for two groups of cows to determine if differences existed in options when different information was included in the analyses. The two groups were all cows with a time to cumulative payoff, and all cows surviving to 96 mo that had a time to cumulative payoff. Discussion of these results will emphasize the most desirable model, evaluated on all cows with a time to payoff. Discrepancies of results with respect to other models, and with other groups of cows will be noted. Sixty-eight percent of the live heifers born in the cow study attained cumulative payoff (9489 out of 13,899).

Significance testing in the cow study differed from the herd study. Because all animals are assumed to be from a single herd, there was no herd by three-way interaction to test differences in involuntary culling, heifer rearing, and sire dystocia. Therefore, these effects were tested by residual error. Testing significance with residual error, combined with the large number of cows in the evaluation (approximately 10,000), renders statistical testing unimportant as most effects in the models will be highly significant. Therefore, discussion of the cow study for the most part will be a comparison of means, regression coefficients, and proportion of variation explained by model components, noting factors that lacked statistical significance.

Using the model containing the 2^3 combination of factors plus cow merit as the covariate, and analyzing all cows with a time to cumulative payoff, cow merit for production and age at first calving were most important, as they accounted for the largest proportion of variation in model mean squares. Several interactions among main effects were significantly associated with time to payoff ($P < .05$), but mean squares for the interactions were small compared with effects of heifer rearing and cow merit, as were differences in least squares means between levels of the interacted effects. Heifers calving at 26 mo paid off 13.5 mo earlier than heifers calving at 32 mo (47.1 vs 60.6 mo), similar to results from the herd study. Mean time to payoff was 53.4 mo. The linear regression of time to payoff on cow merit was -.0077 d/kg, indicating that each 100 kg increase in production reduced time to payoff .77 mo. Mean cow merit was 609 ± 639 kg, so an increase from minus one SD to plus one SD in cow merit was associated with an 9.8 mo decrease in time to payoff.

The main effects of involuntary culling and sire dystocia were significantly associated with time to payoff ($P < .06$), but differences in time to payoff were small, as seen in the results in Table 38 for all cows. Differences in time to cumulative payoff between levels of sire dystocia were less than .1 mo, and 12% involuntary culling had 1.2 mo more time to payoff than 24% involuntary culling. Sire dystocia was associated with small differences in time to payoff because of the low frequency of dystocia, and small difference in dystocia between options. If cows that actually had cases of dystocia were evaluated, rather than the dystocia option, differences may have been more apparent.

Involuntary culling should not be related to large differences in time to cumulative payoff, because if an animal is culled before payoff she is eliminated from the analyses, plus no relationships were included in the simulation model between involuntary culling and production, except through results of events such as mastitis and reproductive problems. The SE's in Table 38 are not equal because there are different numbers of cows appearing in each option. For example, more cows had a time to payoff in the low involuntary culling option because fewer cows were removed as involuntary culls. This does not imply that mean time to payoff between groups would be different, but that a greater number of cows had the opportunity to attain payoff.

From the model containing the 2^3 factors plus the covariate for PD Dollars, the linear regression of time to payoff on PD Dollars was -.0035 d/PD$, indicating bulls with high PD Dollars had daughters that paid off expenses sooner. The mean square accounted for a small amount of model variation, hence the regression was not signifiacant ($P > .10$), although it was approaching significance ($P < .15$). Mean PD Dollars of sires of cows in this study was $108 ± $33. An increase from minus one SD to plus one SD in PD Dollars only changed time to cumulative payoff -.23 mo, which was considerably smaller than the change due to increasing cow merit. PD Dollars is not as important a trait as cow merit, but cow merit contains PD Dollars as well as other production information.

Fitting a model for time to cumulative payoff that contained only effects of the 2^3 combination of factors did little to change results. Most of the model variation was due to the main effect of heifer rearing, the main effect of sire dystocia was not significant, and the R^2 for this model (.31) was lower than the .45 of the model containing the covariate for cow merit. Least squares means for the effects changed little in magnitude, and did not change in rank when this model was used. This supports use of the covariate for cow merit in these analyses.

Table 38. Least squares (LS) means (with SE) for time to cumulative payoff for individual cows, by all combinations of involuntary culling, heifer rearing, and sire dystocia.

Independent Variable[2]			Group Evaluated[1]			
			All Cows		Cows Surviving 96 mo	
Icl	Hfr	Dys	$\bar{x}$	SE	$\bar{x}$	SE
1			54.4	.13	56.0	.19
2			53.2	.13	56.0	.25
	1		47.1	.13	49.0	.23
	2		60.6	.13	63.0	.22
		1	53.8	.13	56.0	.22
		2	53.9	.13	56.0	.22
1	1		48.3	.17	50.1	.26
1	2		60.6	.18	62.0	.26
2	1		45.9	.18	47.9	.37
2	2		60.5	.20	64.0	.35
1		1	53.9	.18	55.4	.26
1		2	55.0	.18	56.7	.26
2		1	53.7	.19	56.6	.36
2		2	52.7	.19	55.3	.36
	1	1	46.8	.18	48.6	.32
	1	2	47.4	.18	49.4	.32
	2	1	60.8	.19	63.3	.31
	2	2	60.3	.19	62.6	.31
1	1	1	47.7	.24	49.3	.37
1	1	2	48.9	.24	50.9	.37
1	2	1	60.1	.26	61.5	.37
1	2	2	61.1	.26	62.5	.37
2	1	1	45.9	.25	47.9	.52
2	1	2	45.9	.26	48.0	.53
2	2	1	61.5	.28	65.2	.49
2	2	2	59.6	.28	62.7	.49

[1] Groups of cows evaluated for time to cumulative payoff were all cows (n = 9489), and cows that survived 96 mo (n = 4208).

[2] Independent variables are: Icl is level of involuntary culling, Hfr is heifer rearing, and Dys is sire dystocia.

The model evaluating time to cumulative payoff for cows that survived 96 mo did not change the rank of least squares means. In all cases mean time to payoff was greater for cows that survived to 96 mo, usually by 1.5 to 2.0 mo (Table 38). Forty-four percent of the cows with a time to cumulative payoff survived to 96 mo, and these cows took longer to attain payoff than all cows, which initally seemed suprising. However, in the cow study cows did not reach 96 mo as a result of selection or voluntary culling, as these components were not included in the simulation model for cows. Cows surviving 96 mo received a salvage value of $700 which would affect their net income but not their time to payoff, as these cows had attained payoff before 96 mo. It is difficult to describe this relationship, unless there is some underlying structure of the simulation that causes cows that payoff earlier to leave the herd earlier. Cows that calve at younger ages payoff earlier, and have more lactations before 96 mo. Since cows are subject to involuntary culling by lactation in this simulation, it seems most likely that a higher proportion of these cows are culled sooner, thus causing the greater time to payoff in cows surviving to 96 mo. Additionally, cows that reach payoff sooner are usually higher producers, so there could be an effect of lower conception rates and longer days open influencing time to payoff, although this effect would probably be minimal.

The regressions of time to payoff on cow merit and PD Dollars were of greater magnitude for cows surviving 96 mo than for all cows with a time to payoff. For time to payoff, the regression for cows surviving 96 mo was -.0099 d/kg, whereas for all cows with a payoff the regression was -.0077 d/kg. Similarly, the regression of time to payoff on PD Dollars was -.0096 d/PD$ for cows surviving 96 mo, but only -.0035 d/PD$ for all cows with a payoff. This appears to be due to increasing importance of production on time to payoff for cows that survived longer, i.e., 96 mo.

Time to cumulative profit was the age of the cow in the beginning month of her first 12 consecutive months of positive cumulative net income. Sixty-nine percent of cows having a time to cumulative payoff had a time to cumulative profit (6590 out of 9489 cows). As such, results of the models evaluating time to cumulative profit will be similar to results from models evaluating time to cumulative payoff, as a large number of the same animals were included in both evaluations. Time to cumulative payoff was 53.4 mo, whereas time to cumulative profit averaged 56.5 mo. Time to profit is later because all cows do not stay positive for the 12 consecutive months after their time to cumulative payoff, although most of them do. Cows that do not remain net positive for 12 consecutive months after payoff usually have a dry period shortly after their time to cumulative payoff.

Results of models evaluating time to cumulative profit for all cows, and cows surviving 96 mo, are in Table 39. The number of cows surviving 96 mo and having a time to cumulative profit was only 30 less than the number surviving 96 mo and having a time to cumulative payoff. The magnitude of values for time to cumulative profit were larger than for time to payoff, but the rank and importance of factors was the same. Using the model evaluating all cows with time to profit, containing the 2^3 factors plus the covariate for cow merit, age at first calving of 26 mo was associated with the largest difference in time to cumulative profit, and was 14 mo less than 32 mo age at first calving. Main effects of involuntary culling and sire dystocia were significant but small, as for time to payoff, and time to cumulative profit was approximately 2 mo longer for cows surviving 96 mo. The R^2 for the model containing cow merit was .44, and for the model without cow merit, .27. This was strong evidence that time to cumulative payoff and time to cumulative profit were equivalent measures, especially when measured on cows surviving 96 mo, because both data sets essentially contained information on the same animals.

The regression of time to cumulative profit on cow merit was -.0097 d/kg. This regression was of the same sign, but larger magnitude than from the model evaluating time to payoff. Increasing cow merit 1278 kg (2 SD) was associated with a reduction in time

Table 39. **Least squares (LS) means (with SE) for time to cumulative profit for individual cows, by all combinations of involuntary culling, heifer rearing, and sire dystocia.**

Independent Variable[2]			Group Evaluated[1]			
			All Cows		Cows Surviving 96 mo	
Icl	Hfr	Dys	$\bar{x}$	SE	$\bar{x}$	SE
1			57.5	.16	59.0	.20
2			56.5	.19	58.9	.28
	1		50.0	.17	51.8	.25
	2		64.0	.18	66.1	.24
		1	56.8	.18	58.8	.24
		2	57.1	.18	59.1	.25
1	1		51.5	.22	53.1	.29
1	2		63.5	.23	65.0	.29
2	1		48.5	.25	50.5	.41
2	2		64.5	.28	67.2	.39
1		1	56.8	.22	58.2	.29
1		2	58.2	.23	59.9	.29
2		1	56.9	.27	59.4	.40
2		2	56.1	.27	58.3	.40
	1	1	49.4	.23	51.1	.35
	1	2	50.6	.24	52.4	.36
	2	1	64.3	.26	66.5	.34
	2	2	63.7	.26	65.7	.34
1	1	1	50.7	.31	52.0	.41
1	1	2	52.2	.32	54.2	.41
1	2	1	62.8	.33	64.4	.40
1	2	2	64.2	.33	65.7	.41
2	1	1	48.0	.35	50.4	.57
2	1	2	48.9	.37	50.7	.58
2	2	1	65.7	.41	68.5	.55
2	2	2	63.2	.39	65.8	.55

[1] Groups of cows evaluated for time to cumulative profit were all cows (n = 6590), and cows that survived 96 mo (n = 4178).

[2] Independent variables are: Icl is level of involuntary culling, Hfr is heifer rearing, and Dys is sire dystocia.

to profit of 12.4 mo, which is a 2.6 mo larger decrease in time to profit in this model from time to payoff from the previous model.

Evaluation of net income per day was done for three groups of cows and with two models. Groups were all cows in the study, all cows that had a first freshening, and cows that survived 96 mo. Models were the same as for objective 1, and either included or did not include covariates for cow merit and sire PD Dollars in addition to the 2^3 combination of involuntary culling, heifer rearing, and sire dystocia. The model of preference is the same as for objective 1, including the covariate for cow merit and its interaction with main effects, but emphasizing evaluation of cows that survived 96 mo with their $700 salvage value included. The $700 represented a lower salvage value than in the herd study, since no voluntary culling was applied in the cow study. Therefore, cows are considered slightly less valuable on the average for dairy purposes.

The model evaluating net income per day at 96 mo, including salvage value, had an R^2 of .52 on 4215 cows. The R^2 from the model evaluating net income per day on all cows with a first calving (n = 11,769) was .13, and for the model evaluating all cows (n = 13,833) the R^2 was .04. As this data set became more restricted a larger proportion of variation was explained by the statistical model. Average net income per day for cows surviving 96 mo was $.85 (Table 40). Model factors associated with the largest mean squares were cow merit and age at first calving. Main effects of dystocia and involuntary culling were associated with small or no differences in net income per day.

An increase of 1728 kg (2 SD) cow merit was associated with an increase of $.48/d of herdlife at 96 mo (b = .00028 $/kg). From Table 40 for cows surviving 96 mo with salvage value, reducing age at first calving from 32 to 26 mo increased net income $.24/d, and random mating of heifers to sires increased net income $.04/d compared with sire selection against dystocia. The small decrease in net income due to selection against dystocia appears to be due to random differences among cows, as PD Dollars of bulls

Table 40. Least squares (LS) means (with SE) for net income per day of herdlife for four groups of cows, by all combinations of involuntary culling, heifer rearing, and sire dystocia.

			Group Evaluated[1]							
Independent Variable[2]			All Cows		Cows Calved		Survived 96 mo[3]		Survived 96 mo[4]	
Icl	Hfr	Dys	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
1			.27	.01	.56	.007	.61	.004	.85	.004
2			.10	.01	.36	.007	.61	.006	.85	.006
	1		.28	.01	.55	.007	.73	.005	.97	.005
	2		.10	.01	.36	.007	.49	.005	.73	.005
		1	.19	.01	.47	.007	.63	.005	.87	.005
		2	.18	.01	.45	.007	.59	.005	.83	.005
1	1		.35	.01	.64	.009	.71	.006	.96	.006
1	2		.20	.01	.48	.010	.51	.006	.75	.006
2	1		.21	.01	.47	.009	.75	.008	.99	.008
2	2		-.004	.01	.25	.010	.46	.008	.70	.008
1		1	.28	.01	.57	.009	.65	.006	.89	.006
1		2	.27	.01	.55	.009	.58	.006	.82	.006
2		1	.11	.01	.36	.010	.61	.008	.85	.008
2		2	.09	.01	.35	.010	.60	.008	.84	.008
	1	1	.30	.01	.59	.009	.76	.007	1.00	.007
	1	2	.26	.01	.52	.009	.70	.007	.94	.007
	2	1	.09	.01	.35	.010	.50	.007	.74	.007
	2	2	.10	.01	.37	.010	.47	.007	.71	.007
1	1	1	.36	.02	.68	.013	.75	.008	.99	.008
1	1	2	.34	.02	.61	.013	.68	.008	.92	.008
1	2	1	.19	.02	.47	.013	.54	.008	.78	.008
1	2	2	.20	.02	.48	.014	.47	.008	.72	.008
2	1	1	.23	.02	.50	.013	.77	.011	1.01	.011
2	1	2	.18	.02	.44	.014	.73	.012	.97	.012
2	2	1	-.01	.02	.23	.014	.45	.011	.70	.011
2	2	2	.01	.02	.27	.014	.47	.011	.71	.011

[1] Groups of cows evaluated for net income per day of herdlife were all cows (n = 13899), cows that had a first calving (n = 11769), and cows that survived 96 mo (n = 4215).

[2] Independent variables are: Icl is level of involuntary culling, Hfr is heifer rearing, and Dys is sire dystocia.

[3] Does not include a salvage value for cows surviving 96 mo.

[4] Includes a salvage value of $700 for all cows surviving 96 mo.

used for matings were similar. Cows with different levels of involuntary culling did not differ in net income per day. The system associated with the largest net income was 26 mo age at first calving, 24% involuntary culling, and random mating of bulls, at \$1.01/d, and the system with the smallest net income was 32 mo age at first calving, 24% involuntary culling, and either dystocia option, at \$.70/d. For cows surviving 96 mo, excluding salvage value on the cows reduced net income \$.25/d, which is a relatively large proportion of total net income per day. Evaluation of all cows with a first calving reduced net income \$.39/d compared with cows surviving 96 mo and including their salvage value, due to the addition of less profitable cows that left the herd before 96 mo. This difference was larger for cows with 24% involuntary culling (-\$.49/d) than 12% involuntary culling (-\$.29/d). The magnitude of this difference was not as large between the levels of heifer rearing and sire dystocia. Including all animals in the evaluation reduced net income \$.66/d compared with cows surviving 96 mo, because of the inclusion of heifers that were never profitable. The model evaluating all animals explained only 4% of the total variation in net income per day. Differences in net income per day were apparent between levels of involuntary culling when all animals or all animals with a first calving were evaluated, but differences did not exist between levels of involuntary culling for cows surviving 96 mo. This appears reasonable, since any cows involuntarily culled early in their life would have large expenses but little or no income to offset the expenses.

Models containing cow merit as a covariate consistently had higher R^2's than models with PD Dollars, or models with no covariate. The R^2's for models with no covariate and PD Dollars as the covariate were .16 for cows surviving to 96, compared with the R^2 of .52 for the model with cow merit. Linear regressions of net income on PD Dollars were positive for the model evaluating all animals (.000627 \$/PD\$) and all animals that calved (.00072 \$/PD\$), but negative for cows surviving 96 mo (-.00016

S/PDS). Since involuntary culling was random, cows with higher ability to produce milk could have been culled first.

The magnitude of net income is important to profitability of cows, but another area of interest is the disposition of this income over time. Figure 13 contains a plot of monthly net income to 150 mo of age, by age at first calving, averaged over all options. Net income per month was lowest in calves from birth to weaning, due to the high cost of milk, milk replacer, and starter. Calves after weaning cost less per month to raise, but as they get older they consume larger quantities of feed and increase in monthly expense, i.e., the slope of the curve in Figure 13 is negative from weaning to first calving. After calving, cows begin to have positive net income each month except for their dry period. Peaks and valleys occur in the monthly net income curve depending on the number of cows milking and dry at one time. Thus, as cows get older (> 100 mo) the curve smooths out because cows are in all stages of lactation.

Figure 14 shows the relationship of net income by age on a cumulative basis. Cows steadily decrease in cumulative net income until their first calving, and then steadily increased in net income for the duration of their lifetime, crossing zero at the time to cumulative payoff. The plot in Figure 14 shows averages by age at first calving for all cows in the study alive at each month, so the effect of the dry period of individual cows is not apparent. For individual cows, cumulative income would decrease each dry period, as no income is received.

A different way to evaluate net income is on a lactation or event basis, rather than on age. This was the purpose of objective 3 of the cow study. From birth, lifetime events for heifers were weaning, pregnancy, and calving; and for each lactation of cows events were calving, 70 d in milk, 140 d in milk 210 d in milk, dry off, and the next calving. A calving was considered the end of one lactation, and also the beginning of the next, so some overlap occurred. Cumulative net income per day of herdlife was

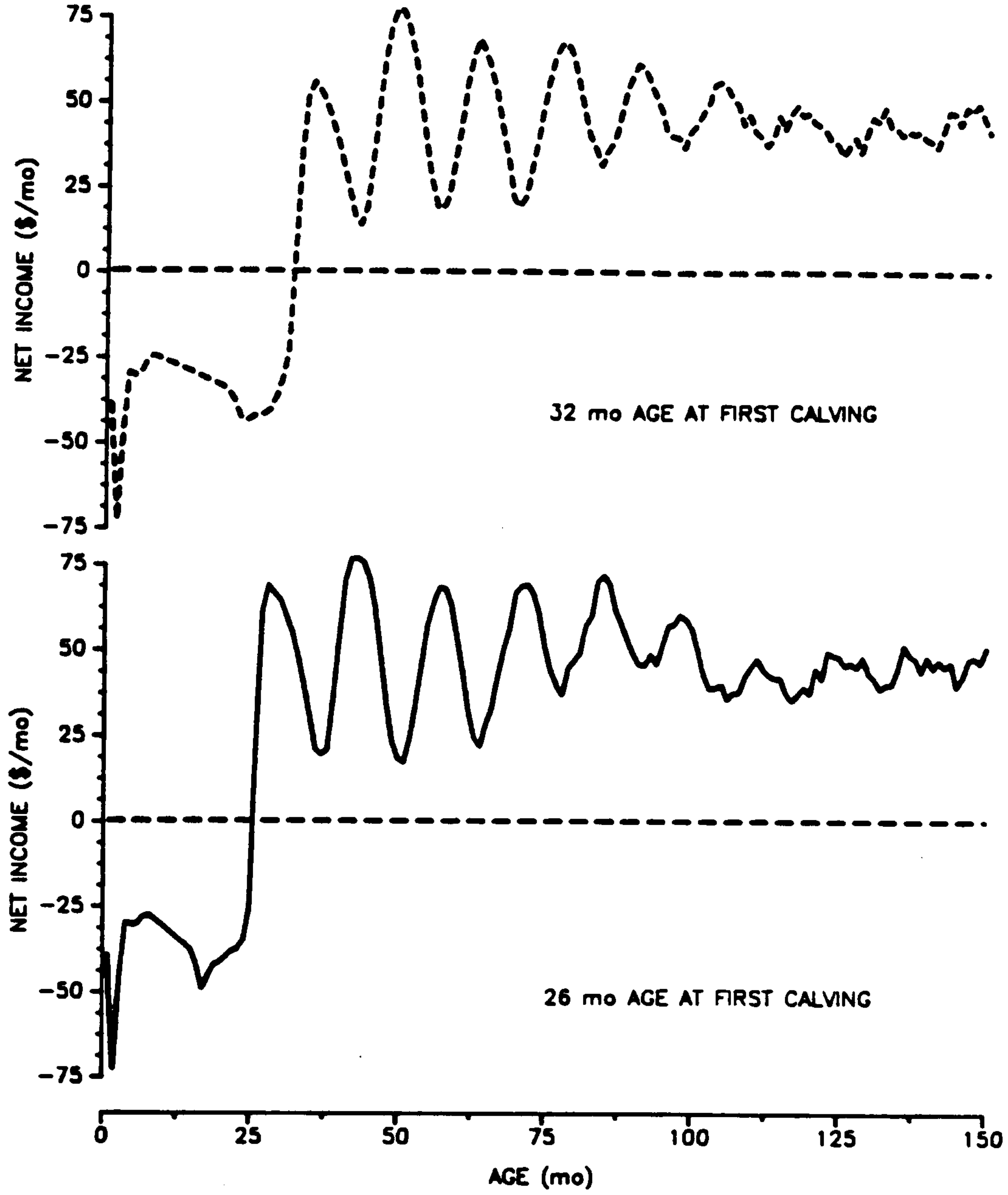

Figure 13. Plot of monthly net income by age for animals in the cow study.

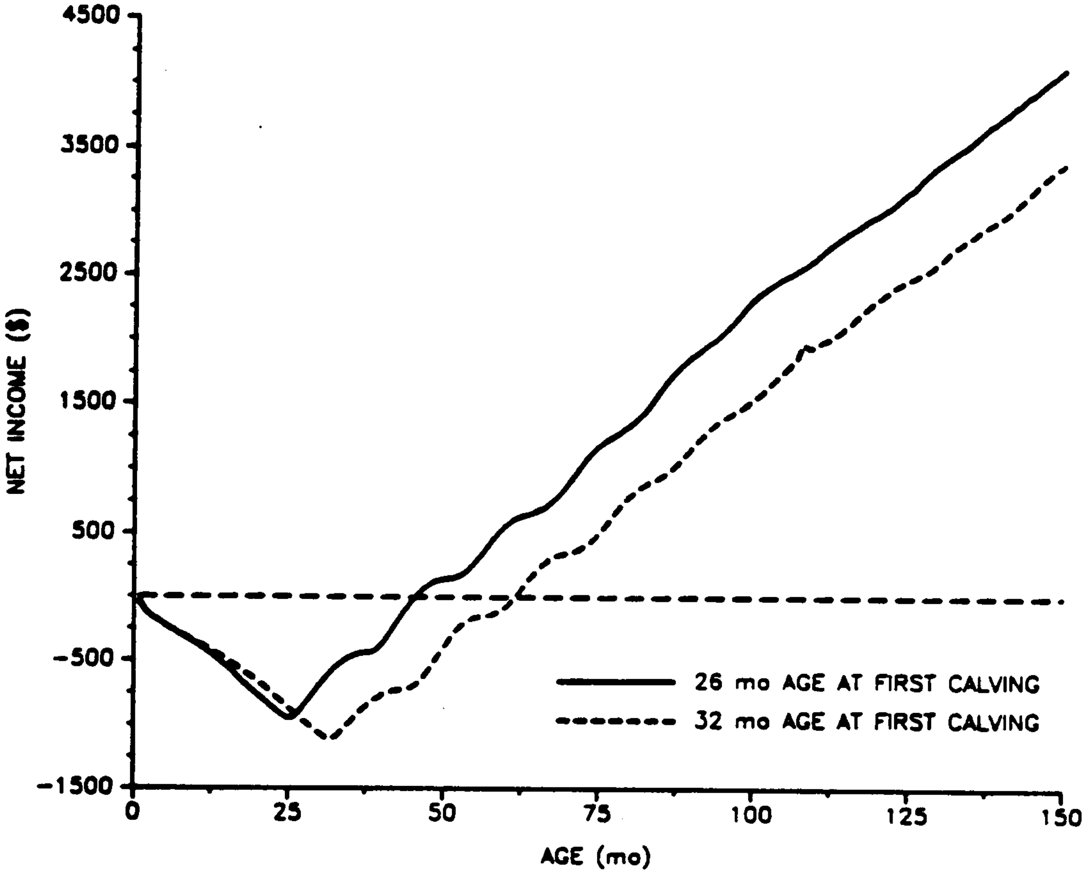

Figure 14. Plot of cumulative net income by age for animals in the cow study.

calculated at each event for all cows, and compared across options. Table 41 lists mean net income per day of herdlife for events of animals through four complete lactations.

Models were analyzed separately for heifers, and for each of the first four lactations on cows to identify factors related to net income on an event basis. For heifers, three events were evaluated: They were net income per day at weaning, pregnancy, and first calving. For each lactation on cows, events started with calving and went through the next calving. The model dependent variable was net income per day of herdlife, with herdlife measured as days from birth to the current event. Independent variables were the 2^3 combinations of involuntary culling, heifer rearing, and sire dystocia, plus a categorical effect for event, plus covariates for cow merit and sire PD Dollars.

In the model evaluating net income per day for heifers, the R^2 was .88, with almost all of the variation attributed to differences in events. Small differences for net income per day were found for levels of heifer rearing, and the interaction of heifer rearing with event. Events differed for heifers, with net income lowest at weaning due to the high cost of milk and milk replacer combined with the relatively few days from birth to weaning. The small difference in net income per day between heifer rearing options is probably due to early calving heifers having faster growth rates, and thus higher daily costs. Heifers calving at 26 mo had lower net income per day of herdlife (-\$1.31) compared with heifers calving at 32 mo (-\$1.24), an advantage of \$.07/d for older calving heifers. However, heifers calving at 32 mo were 180 d older at first calving, and cost more to raise on a total expense basis than indicated by the per day expense. No other effects were related to net income per day in heifers, which was expected because differences due to other effects were not included in the simulation until after first calving.

For the model evaluating cumulative net income per day for events of cows in their first lactation, the R^2 was .83, which was lower than the R^2 for heifers. Subsequent models for second and third lactations had R^2 of .68 and .59, respectively. As lactation

Table 41. Means (with SD) for net income per day of herdlife for all cows at specified events through four lactations, by option and event.

Event	Option[1]															
	111		112		121		122		211		212		221		222	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Calves																
Weaning	-2.41	.31	-2.39	.31	-2.39	.30	-2.41	.30	-2.40	.30	-2.40	.30	-2.41	.30	-2.40	.30
Breeding	-1.25	.17	-1.24	.18	-1.12	.15	-1.12	.15	-1.25	.18	-1.23	.19	-1.12	.14	-1.12	.15
First Lactation																
Calving	-1.32	.05	-1.32	.05	-1.24	.03	-1.24	.03	-1.31	.05	-1.31	.05	-1.24	.03	-1.24	.03
70 DIM	-.83	.13	-.85	.14	-.90	.10	-.88	.11	-.86	.12	-.82	.14	-.88	.09	-.87	.10
140 DIM	-.62	.15	-.63	.15	-.75	.11	-.72	.12	-.66	.14	-.59	.15	-.73	.11	-.71	.11
210 DIM	-.47	.17	-.48	.17	-.65	.12	-.61	.13	-.52	.15	-.43	.18	-.62	.12	-.60	.12
Dry	-.32	.24	-.32	.24	-.53	.18	-.47	.21	-.38	.22	-.26	.26	-.51	.17	-.46	.20
Second Lactation																
Calving	-.46	.18	-.47	.17	-.65	.12	-.60	.14	-.52	.15	-.42	.19	-.62	.12	-.60	.13
70 DIM	-.12	.20	-.10	.20	-.32	.15	-.31	.16	-.17	.18	-.08	.21	-.31	.15	-.29	.16
140 DIM	.02	.21	.07	.22	-.17	.17	-.18	.17	-.02	.20	.06	.21	-.17	.16	-.15	.17
210 DIM	.09	.22	.17	.23	-.07	.18	-.11	.17	.06	.21	.14	.23	-.09	.17	-.07	.19
Dry	.10	.25	.22	.28	-.03	.22	-.07	.22	.08	.24	.16	.26	-.05	.21	-.03	.23
Third Lactation																
Calving	-.04	.21	.05	.23	-.15	.19	-.21	.17	-.06	.20	.00	.22	-.18	.17	-.17	.19
70 DIM	.21	.22	.29	.24	.07	.20	.00	.18	.18	.22	.24	.23	.05	.18	.06	.20
140 DIM	.32	.23	.40	.25	.17	.21	.09	.19	.27	.23	.35	.24	.14	.19	.15	.21
210 DIM	.38	.24	.44	.25	.23	.21	.13	.20	.31	.23	.40	.25	.19	.20	.20	.22
Dry	.37	.26	.45	.29	.23	.24	.13	.22	.29	.26	.40	.27	.19	.22	.21	.26
Fourth Lactation																
Calving	.24	.24	.29	.25	.11	.22	.00	.20	.16	.23	.25	.24	.08	.20	.07	.22
70 DIM	.46	.25	.48	.26	.30	.23	.20	.21	.36	.24	.46	.25	.26	.21	.25	.23
140 DIM	.55	.26	.56	.27	.38	.23	.29	.22	.44	.25	.55	.26	.34	.22	.33	.23
210 DIM	.60	.27	.60	.28	.42	.24	.34	.23	.48	.25	.61	.26	.38	.22	.37	.24
Dry	.60	.28	.61	.29	.43	.26	.36	.26	.48	.27	.62	.29	.39	.24	.38	.26
Calving[2]	.49	.26	.47	.27	.32	.24	.24	.23	.37	.25	.48	.26	.28	.22	.27	.24

[1] Options are 2^3 combinations of involuntary culling, heifer rearing, and sire dystocia.

[2] Calving that ends the fourth, or begins the fifth lactation.

increased, model variation due to event decreased, with a corresponding increase in variation due to cow merit, implying more emphasis was placed on cow production, rather than event, in later lactations. For lactation one through three, the regression of net income on cow merit within lactation increased from .0006 $/kg to .0020 $/kg, a result of accumulating income over the cow's lifetime due to production. Age at first calving was associated with net income per day in all lactations, as well as the interaction of age at first calving with event. The significant interaction of age at first calving with event was due to heifers calving at 26 mo costing more per day to raise, combined with their ability to payoff faster and gain in net income faster after first calving. This was due to their younger age and less total cost at first calving. The increasing importance of cow merit with increasing lactations was due to the importance of production on net income, which accumulates over time.

On a lactation basis, most options attained positive net income per day during the second lactation. Options with 12% involuntary culling, 26 mo age at first calving, and selection against dystocia (option 112 in Table 41), and 24% involuntary culling, 26 mo age at first calving, and selection against dystocia (option 212 in Table 41) attained positive net income by 140 d in milk of the second lactation, and remained positive after that time. Options with 12% involuntary culling, 32 mo age at calving, and random mating (option 121), 24% involuntary culling, 32 mo age at calving, and random mating (option 221), and 24% involuntary culling, 32 mo age at calving, and selection against dystocia (option 222) did not attain positive net income until 70 d in milk of the third lactation. This was due mainly to age at calving of 32 mo. Other options attained a net positive net income in the second lactation, went negative during the dry period following lactation 2, and went continually positive at 70 d in milk of the third lactation (Table 41). Options with 26 mo age at first calving (second digit of the option in Table 41 is a 1) had net income per day at first calving of -$1.31 to -$1.32. This was lower by $.06 to

$.07/d than for heifers calving at 32 mo, meaning that it cost more to raise heifers to 26 mo calving on a daily basis. However, heifers calving at 26 mo had 180 d less herdlife at first calving, and were able to recoup this difference quickly, usually by 70 d in milk of the first lactation. This was reflected in the significant interaction of age at first calving with event, as shown in the results in Figure 15.

Differences among options in net income per day for the main effects of involuntary culling, heifer rearing, and sire dystocia are difficult to identify from data in Table 41, because the main effects are distributed over several options. Plots in Figures 15, 16, and 17 show the relationship of net income per day on lifetime events through four lactations for different levels of heifer rearing, involuntary culling, and sire dystocia, respectively. The plot of net income per day on events through four lactations for different levels of age at first calving (Figure 15) illustrates the significant interaction of age at calving with event. Heifers calving at 26 mo cost $.07/d more to raise, but had offset that difference by 70 d in milk of the first lactation. These heifers increased in net income per day faster than heifers calving at 32 mo, especially in the first two lactations. This resulted in heifers calving at 26 mo attaining payoff sooner than heifers calving at 32 mo. Heifers calving at 26 mo paid off at 140 d of their second lactation, whereas heifers calving at 32 mo paid off at 70 d of their third lactation.

Figure 16 plots net income per day of herdlife on events over four lactations in cows for the two levels of involuntary culling. Small differences exist between 12 and 24% involuntary culling in the first and second lactations, but not in heifers or in later lactations. Cows attained payoff near the end of their second lactation, were negative during the dry period between lactations two and three, and went continually positive in their third lactation. The main effect of involuntary culling was not associated with net income per day, nor was the interaction of involuntary culling with event significant, so the lines in Figure 16 are considered parallel and not different. Figure 17 plots the

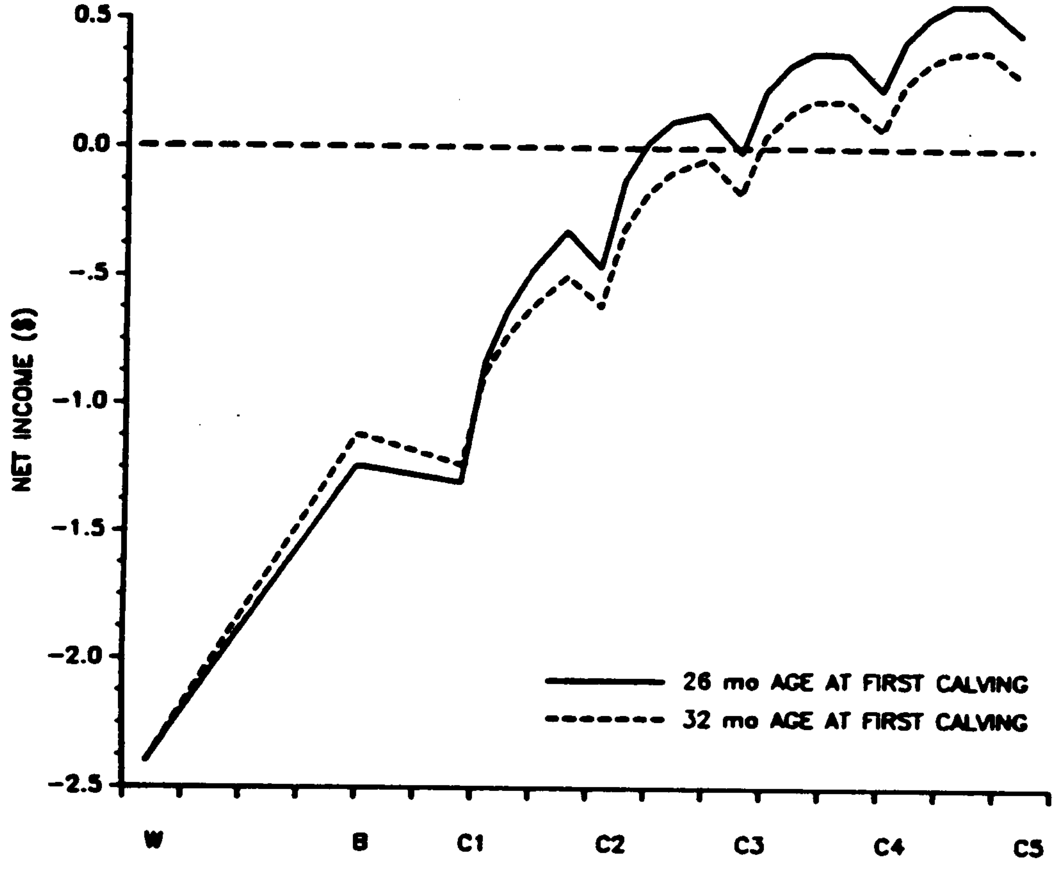

Figure 15. Plot of net income per day of herdlife by event through four lactations for levels of heifer rearing. Events are: W = weaning, B = breeding, and C1-C5 are consecutive calvings.

relationship of net income through four lactations on events for different levels of sire dystocia. Differences in levels of sire dystocia on net income were not observed, similar to the result for involuntary culling. There is a slight difference in lines of the plot in Figure 17 for lactations three and four, but this difference is small.

The final objective of the cow study evaluated the relationship of the number of cases of mastitis, days dry, days open, and number of services per conception with net income of cows. Independent variables number of mastitis cases, days dry, days open, and number of of services per conception were measured per lactation using completed records, so not to discriminate against cows with more lactations or partial lactations. Net income was per day of herdlife, with herdlife measured in days from birth. The independent variables were continuous with linear regressions fit on them. Separate models included regressions on cow merit and sire PD Dollars, plus interactions between cow merit, PD Dollars, and the independent variables.

The average cases of mastitis per lactation was .78, ranging from 0 to 4 cases. The model predicting net income per day from the number of mastitis cases and cow merit had an R^2 of .21, and the model with PD Dollars as the covariate had an R^2 of .05. Number of mastitis cases, cow merit, and the interaction of mastitis cases with cow merit were significantly associated with net income per day. The linear regressions of net income on cow merit, mastitis cases, and their interaction were all positive. The regression of net income on cow merit was .00023 $/kg. The expected regression of net income on mastitis cases should be negative, since cows with mastitis have less milk income, more treatment costs, and lower milk yield after mastitis. The regression of net income on mastitis was .146 $/case, however. One explanation of this relationship is that there are more mastitis cases in older cows, but also higher milk yield. Cow merit only accounts for differences between cows, not changes within cows as they age. This is supported by data of Stott and DeLorenzo (79), as they reported that days of discarded milk in-

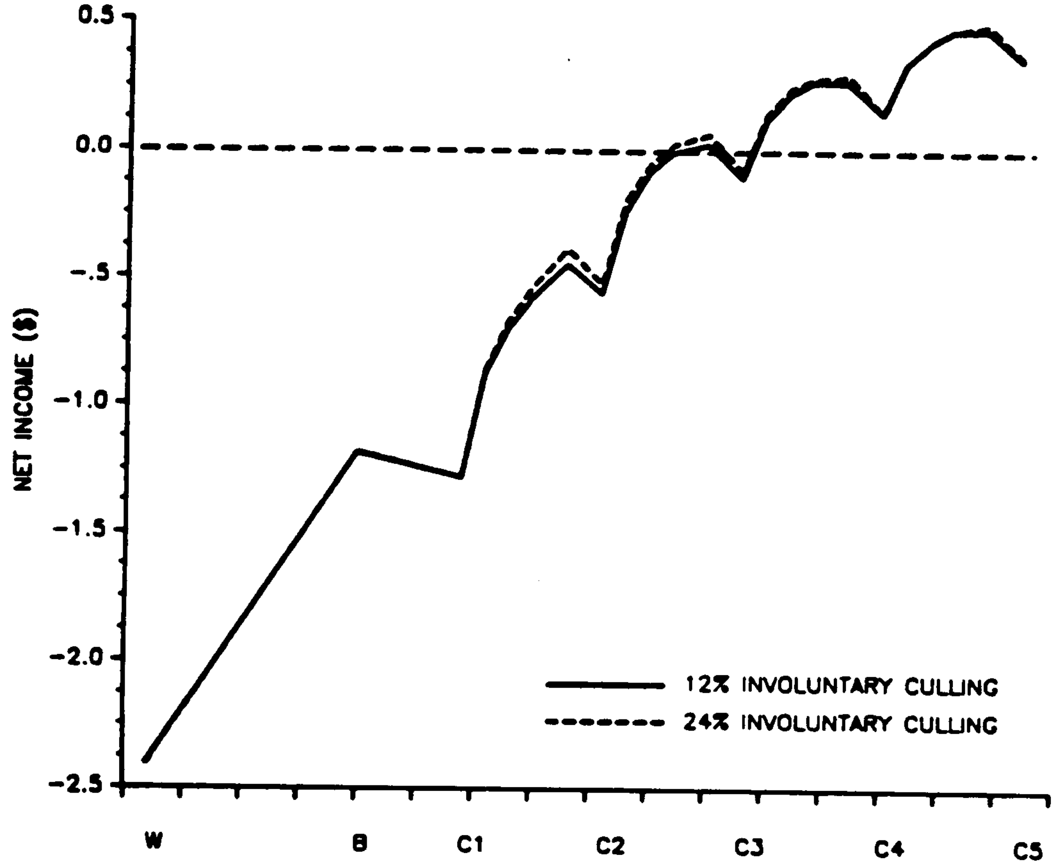

Figure 16. Plot of net income per day of herdlife by event through four lactations for levels of involuntary culling. Events are: W = weaning, B = breeding, and C1-C5 are consecutive calvings.

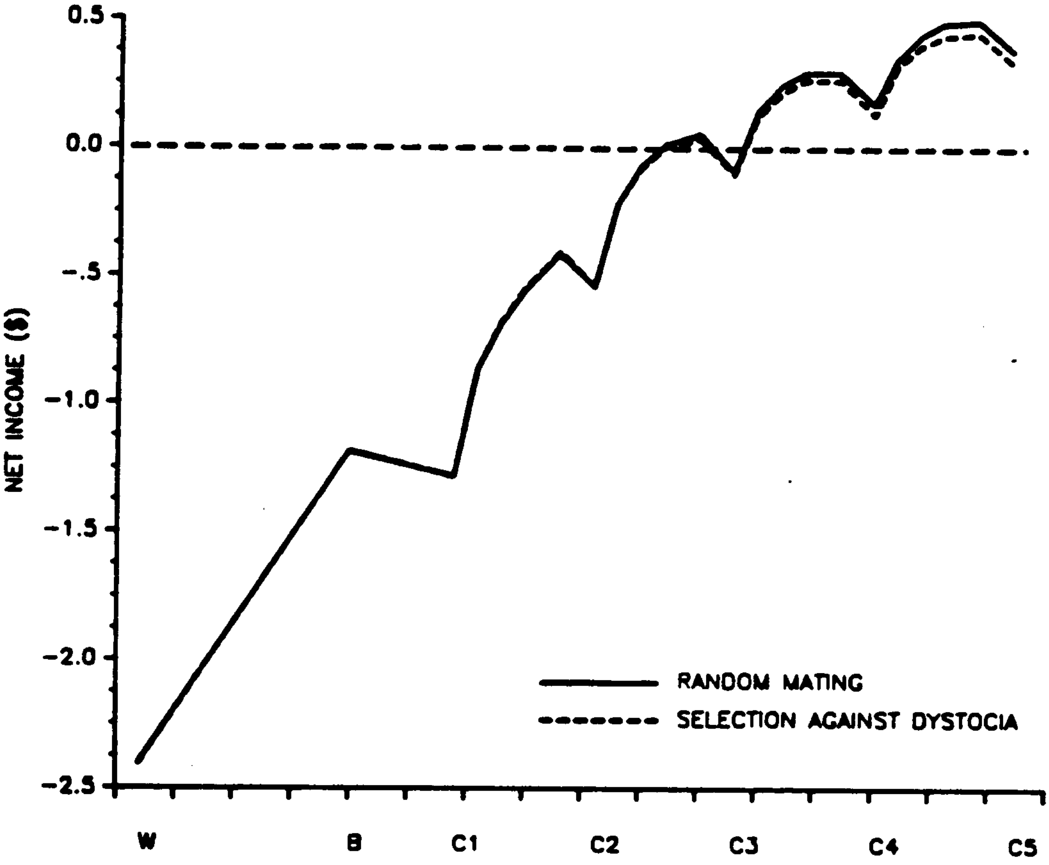

Figure 17. Plot of net income per day of herdlife by event through four lactations for levels of sire dystocia. Events are: W = weaning, B = Breeding, and C1-C5 are consecutive calvings.

creased from 2.6 to 13.1 d as lactation number increased from 1 to 6, but milk yield increased from 7731 to 8264 kg during that same time. From work of Bertrand et al. (8), daughters of high PD Milk sires had 42% higher total discarded milk costs, but 15% more profit per lactation. Perhaps a more correct model would have evaluated this relationship within lactation, rather than across lactations. The regression of net income on the interaction of mastitis cases with cow merit was positive but small (.000038 $/kg case), implying that cows with higher milk yield had more net income per day of herdlife, even though they had more mastitis. PD Dollars was not significantly associated with net income ($P > .10$), and the regression of net income on PD Dollars was .00021 $/PD$.

In the model evaluating the average number of days dry with net income, the R^2 was .19, with the regression on days dry, and the interaction of days dry with cow merit significantly associated with net income per day. The regression of net income on average days dry was .007 $/d, an indication that higher producing cows that had more income also had more days dry. Included in this relationship were segments in the simulation model that decreased milk yield in the lactation following a short dry period, in accordance with Funk et al. (34). Funk's research found a large decrease in milk yield in lactations that followed a dry period of less than 60 d. The regression of net income on the interaction of days dry with cow merit (.000003 $/kg d) indicated that as production and days dry increased, there was a small additional increase in net income per day. Average days dry was 71 d, and ranged from 31 to 109 d. The model including PD Dollars had an R^2 of .04, with days dry significantly associated with net income per day.

Cows with fewer days open had more net income per day of herdlife, because they had less days of low yield later in lactation. The R^2 for this model was .16, with effects of days open and cow merit significant ($P < .10$). Average days open was 138 d, ranging from 51 to 309 d. The linear regression of net income on days open was -.0013 $/d, meaning an average decrease of 10 d open over a cow's lifetime would result in increased income of .013 \$/d. The average net income for cows in this study was \$.63/d, so the effects of days open were relatively small. The regression of net income on cow merit was .00023 \$/kg, as with the mastitis model. The R^2 for the model containing PD Dollars was .01, and although PD Dollars and the interaction of PD Dollars with days open were significantly related to net income ($P < .10$), the variation explained by the model was minimal.

The model evaluating the relationship of net income with number of services per conception also had an R^2 of .16. Factors related to net income were number of services and cow merit. The regression of net income on number of services was negative (-.067 \$/service), indicating that cows with fewer services were more profitable. This would be expected because fewer units of semen were used. Assuming that breeding started at the same time and heat detection was equivalent among cows, cows with fewer services would be related to fewer days open, which would also be a contributor to increased net income. Average number of services was 1.65, and ranged from 1 to 7 services. Less than 1% of model variation was explained by the model containing PD Dollars and number of services per conception.

The models evaluating the relationship of net income with mastitis, days dry, days open, and number of services per conception were characterized by somewhat low R^2's (.16 to .21), although independent variables in the models were significantly related to net income. Including cow merit in the models accounted for a large proportion of this variation. These models do not provide an in-depth evaluation of the independent variables, but do present a general overview of relationship between net income and the independent variables.

Conclusions

Utilizing simulation to investigate the impact of options representing various aspects of dairy herd management strategies, heifer rearing, or more specifically age at first calving, was the most important factor influencing differences in time to cumulative payoff of expenses and profit per day of herdlife. The large magnitude of differences in response variables as age at first calving was reduced from 32 to 26 mo is an indication of its importance. Part of the magnitude of these differences is due to the additional 6 mo of heifer rearing, which is a large difference, but still within the range of values found on many dairy farms. The economic advantage of having heifers calve earlier is in their lower cost at calving, and also in the capability of these heifers to return profit sooner because of their younger age at first calving. Values reported for net income are inflated because interest on average investment was not included in net income in this study.

The range of involuntary culling used, 12 to 24%, was also a large range, but differences in time to payoff of expenses and net income per day across levels of involuntary culling were much smaller than for age at first calving. With this range of values for involuntary culling, one would expect large differences in response variables, especially net income, since voluntary culling was based on net income. Differences in response across levels of involuntary culling were not as large as for age at first calving for the following reasons. Most important, differences in age at first calving affected all heifers in the herds. On the other hand, with 30% total involuntary culls per year, 24 animals out of 80 would leave the herd each year. In the 12% involuntary culling option 10 of the 24 animals leaving would be involuntary, and in the 24% option 20 of the 24 animals would leave involuntarily. The difference between the two options, 10 animals, have to account for all of the difference in net income and time to payoff. In addition, it is not just the disposition of 10 animals, but the difference in value between the 10 involuntary culls and 10 voluntary culls that would replace them. Finally, differences in response variables are minimal because of the nature of voluntary culling in this simulation. Differences in profit per animal day between levels of involuntary culling were larger than for time to payoff, because cows survived longer in the 12% involuntary culling option. When the opportunity existed to cull cows voluntarily, only cows greater than 200 d in milk and not dry were considered for culling. Thus, the poorest cows in the herds would not always be culled.

The effect of different levels of selection against dystocia on time to payoff and net income were minimal in this simulation due to the type of mating program used. By randomly mating a group of heifers to a large group of bulls, the expected percent difficult births in heifers would be near the mean of the bull's values for difficult births. Bulls selected as calving ease sires were only about 3% superior (6% versus 9%) for calving ease than the entire group of bulls. Calving ease bulls were only used on heifers, representing approximately 30% of the total herd. Thus, the difference in dystocia occurrence between options was only about 1%, which, in retrospect, was not large enough to create a measurable difference in response variables.

The other important factor in this study was level of milk yield. Milk yield can either be classified as a herd characteristic, as in permanent herd milk yield, a cow characteristic, as the sum of breeding value, the permanent herd effect, and the permanent environmental effect, or as a sire trait, as in genetic trend over time. It can also be continuous or categorical. All of these production measurements were important, and all were associated with large changes in time to payoff and income per day. It might be argued that changes in yield due to management decisions are temporary. Regardless, including milk yield defined income after inclusion of the factors, and the factors, particularly age at first calving, still show differences in time to payoff and net income with milk yield held constant. It can be argued that environmental effects are not transmitted across generations, but they have a large and measurable influence on net income.

The most important interactions in this simulation involved the interaction of age at first calving with milk yield for time to payoff and net income per day. One might expect the combination of 26 mo age at first calving and high yield to be most profitable, which they were, but changes in time to payoff decreased faster and net income increased faster at 32 mo age at first calving when yield increased. It is possible that limiting factors existed for 26 mo age at first calving that slow down the rate of progress in net income. Other combinations of factors had significant interactions, but differences in response of net income and time to payoff were small enough to render the impact of the interactions unimportant.

Model dependent variables, time to cumulative payoff and net income per day, are important measures with respect to profitability of the dairy enterprise. The magnitude of net income, regardless of how it is measured, is an indication of return of money to the farm after expenses, and certainly is an important measure. Time to payoff is important because money received earlier can be reinvested, and has more value on a present value basis. A problem with these analyses is that net income per day and time to payoff, as well as several other measures used in this study, tend to evaluate the same parameters. Perhaps in future analyses, more widely differing types of variables could be evaluated.

A valuable conclusion from these analyses is the identification of management strategies that are important to profitability of dairy herds. Reducing age at first calving to 26 mo requires more intensive management of heifers, but actually costs less to raise heifers to calving on a total cost basis than raising heifers to 32 mo, and the heifers return money to the operation sooner. Although differences in net income and time to payoff between levels of involuntary culling are not as large, any time an unprofitable animal can be replaced with a more profitable animal, a correct decision has been made. Avoidance of dystocia in heifers is desirable, and can be attained through the use of a few calving ease bulls or through use of a large group of bulls. Finally, almost any management decision that has the capability to improve production would be benefical to profitability in some manner, as fixed costs of many aspects of the farm operation do not change, and variable costs of increasing production rise at a slower rate than increases in income as a result of management changes.

One of the larger problems involved with this study is the lack of interactions included in components of the simulation model, either because of a lack of knowledge or current programming limitations. Specific relationships that are considered important, but are lacking in the simulation are relationships between nutritional status, milk yield, and health occurrences. Currently, milk yield and health are not a function of inadequate feeding. All cows receive what they require. Another desirable relationship not currently in the simulation would be to incorporate differences in cost structure for different levels of herd milk yield. There is much room for improvements to be made in this model, and changes will be made over time as new equations are incorporated into the model, current procedures are refined, and interactions among model segments are developed.

With regard to nutritional information, all cows are currently fed according to requirements of the National Research Council (55). One of the more important factors associated with consistent high production is providing high quality feeds in the appropriate quantities, which is done by the current simulation. However, many dairy producers provide neither balanced rations nor have feeds of ideal quality. The capability for the user of this simulation to balance rations and supply information to the simulation regarding rations, quality of feeds, feeding recommendations, and ingredient costs would be desirable from a research, as well as an instructional standpoint. A problem with the current simulation is that all herds were operated under the assumption of consistent management. Variability in the nutritional program would approximate differences in management within as well as between herds.

The consequences of dystocia are well defined and relatively complete in this simulation from a sire standpoint. No effects of dystocia due to cows are currently included in the program, although it is difficult to determine cow effects on dystocia after bull effects have been considered. It would seem desirable to include a cow effect for dystocia, especially for heifers that are poorly grown. Compared with dystocia, other diseases and conditions are not as well developed in this simulation. In particular, mastitis occurrence and recurrence need more development. This simulation has an acceptable method for predicting clinical, but not subclinical mastitis. Incorporation of somatic cell count information would seem to be the best way to estimate subclinical mastitis and milk loss due to subclinical mastitis, as well as predict clinical mastitis. In this simulation contraction of mastitis was not related to milk yield. In the future it would seem desirable to include this relationship. Other diseases that were predicted in this simulation, such as milk fever, ketosis, and displaced abomasum, did not have relationships included with production, nutritional status, or combinations of these factors. Addition of interrelationships between common diseases, and of diseases with production and management alternatives, would be beneficial.

Perhaps one of the most important aspects lacking in this simulation is the calculation of genetic and phenotypic evaluations on cows and bulls. Because of the nature of this simulation, i.e., herds could be run on several computers independently by different people, records from all cows and all herds may not be available at a given time to one person, thus making animal evaluations difficult. Additionally, much of the overhead in current simulations is due to programming involved in sire and cow evaluation subroutines, as sums, averages, and deviations have to be carried across cows, herds, and years. It seems most desirable that sire and cow evaluations be from stand alone programs. Animal model applications are currently being developed and some will be available for microcomputers. Addition of a sire and cow evaluation program to read records from this simulation and provide necessary evaluations would be of most benefit for teaching and research purposes.

Financial information is very important to herd management applications. While this simulation collects and stores net income on a monthly and lactation basis for a variety of variables, none of this information is currently incorporated into standard financial forms such as profit and loss statements and balance sheets. These additions would be desirable from an instructional standpoint.

Development of a microcomputer simulation for evaluation of dairy herd management strategies is a computationally intensive project. Creation of each initial 80-cow herd required approximately 40 s on a Compaq microcomputer with an 80386 microprocessor, operating at 20 MHz clock speed. Simulation of progression of one herd, and all cows and calves in it, through one year took approximately 4 min. Therefore, simulation of one option, consisting of 20 herds moving through 20 simulated years, took 30 h to compute. Data files for storage of monthly records, completed records, and herds occupied 80 to 100 MBytes of storage space, of which 20 MBytes of data were transferred to the mainframe computer for statistical analyses. Transfer time of these records was approximately 16 h at 4800 baud. Simulation of 1000 cows through their lifetime required 7 h. File sizes containing information on the cows totaled 4 MBytes, and transfer time was about 3.5 h. It is feasible to operate such a simulation on a microcomputer, particularly if it is only necessary to simulate one year, or one herd at a time.

Development of this simulation is the first step toward developing a complete dairy management simulation capable of evaluating a variety of management situations for research and teaching purposes. Several desirable characteristics of simulation and dairy management decisions have been included in this program, although many aspects of the simulation require further development.

Finally, one should note that while evaluating many options and making several management decisions concurrently, the ability to see the result of a single decision is diminished. This is a two fold problem since it is important to determine results of individual characteristics to rank their importance, but individual decisions must be combined to develop a management program. Successful dairy herd managers make many good decisions consistently, and it is the combination of these decisions that determines success of the enterprise.

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