DEVELOPMENT AND EVALUATION OF AN EXPERT SYSTEM
FOR USE AS AN AID IN CULLING DAIRY CATTLE

by

Max L. Checketts

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Max Lynn Checketts
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ABSTRACT

Development and Evaluation of an Expert System for Use as an Aid in Culling Dairy Cattle

by

Max L. Checketts, Doctor of Philosophy
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Major Professor: Dr. Robert C. Lamb
Department: Animal, Dairy and Veterinary Sciences

An expert system for identifying cows to be culled, MAXCULL, was programmed to run on an IBM or compatible personal computer. It was designed to be used with Dairy Herd Improvement (DHI) records as an aid in decision making. MAXCULL used fifty-two health, seventeen reproduction, and thirty-nine production rules in the analysis.

MAXCULL was initially developed using two expert system tools. VP-Expert and Super Expert both had inductive abilities and were reasonably priced. VP-Expert was selected to continue the development of the MAXCULL system. The program used a rule-based method of storing knowledge, which was obtained from literature reviewed in the health, reproduction and management areas. Three blocks of rules were developed. MAXCULL used a backward-chaining control strategy.

The information on each cow was obtained from a special report obtained from DHI Provo. The diagnosis from MAXCULL
produced an explanation paragraph identifying possible reasons for removing the cow. Twenty herds with DHI records were identified, ten assigned as controls and ten to be evaluated with the MAXCULL system. General linear model procedures were used to compare thirteen variables after using MAXCULL for one year. No significant differences were noted for any of the variables. The chi-square analysis showed that the decisions of MAXCULL were significantly different from the decisions of the manager. The final survey supports the idea that dairy management expertise can be provided to the dairy manager through an expert system.
The objective of most dairymen is to return a profit large enough to constitute a comfortable living. Dairymen who effectively observe three management functions improve their chances of profitability and of remaining in business for the long term. First, the entire dairy operation must be evaluated to determine the status of management of the total herd. Second, each cow must be individually evaluated to determine which cows are making money. Third, management decisions must be based on the information obtained through the first two functions.

Dairymen have used many different methods to cull cows that were not profitable. Over time, as they kept better records, dairymen noticed that cows were removed from the herd for various reasons. Some of these were at the discretion of the dairyman, while others were involuntary. Low milk production was identified as the primary voluntary reason for removing an animal; removing low producing animals from the herd increased the dairyman's income. Cows were normally involuntarily culled for reproductive problems, various diseases such as mastitis, and injuries or other problems that hampered the producing ability of that animal.

Dairymen have sought to minimize the involuntary losses of animals from their herd so that they can maximize the opportunity to remove cows which contribute the least to the
profit of the dairy farm. Studies (3,14,15,17,32) have shown that as dairymen are able to reduce involuntary culling and increase voluntary culling they increase the profits from those animals remaining. Other investigators (1,50,51,62,71) have found that initially dairymen looked at production records to remove animals. As records have become more accurate, dairymen have looked for other sources of information to determine which animals are to be removed from the herd.

Researchers (7,9,10,13,24,30) have attempted to develop several general means to assist dairymen in culling animals to improve profits. Usually the herd manager has his own set of reasons or values as to why animals need to be removed from the herd. As herd size increases, complete information on individual cows can no longer be stored in the herdsman's or manager's own memory. As a result, decisions are often based on incomplete information.

Although it appears easy to identify cows to be removed, in reality the information needed can be difficult to collect and even more difficult to use in an objective manner.

As herd size continues to increase, methods need to be developed that can aid the dairy producer in classifying animals for different management purposes. Dairymen specifically need the means to identify individual cows to be removed from the herd.
The dairyman, with no additional capital outlay, can have a drastic effect on both short-term and long-term profits by using proper culling techniques (36). However, culling at the wrong time, the wrong cow, or too many cows will have an effect on the long-term ability of the farm to stay in business. A balance must be maintained between the information essential to culling decisions and that information which could be helpful but is more difficult to obtain. The culling decision is a continuing process of gathering facts or data and then making judgments about future profitability of those animals.

Managers have encountered increased pressure to make sound production decisions and to increase efficiency in order to yield adequate profits. Advanced computer-based technologies offer unique opportunities to provide quantitative decision-making support to managers and herdsmen. Much of the agricultural software that has been developed has not been accepted and used by farmers. This could be for several reasons, two of the most obvious include fear of computers and lack of understanding of how computers operate.

Recent advances in artificial intelligence have created opportunities for the development and implementation of computer applications for managing dairy enterprises. Specifically, an area of artificial intelligence known as expert systems has shown promise. Expert systems make it possible for computers to perform some functions that
historically were limited to human reasoning alone. Knowledge engineering can be used to acquire knowledge from those who have abilities in a particular area. The knowledge is then used to create rules or sets of rules for solving problems or making decisions such as culling cows.

Expert systems could be used to record the decision process of each manager or herdsman. These systems could be useful in obtaining specific expertise from those who have studied the problem of culling unprofitable cows. The advice provided could be comparable to that of the human expert. No computer knowledge is required by someone using the system. The natural language interface used could make the consultation with the computer a very natural process. This would help alleviate some of the problems of acceptance of computers and computer software by agricultural managers.

Expert system software is composed of three main parts. The first two parts, consisting of the user interface and the inference engine are frequently called an expert system shell. The first part, the user interface, performs steps that allow the user to interact with the computer. The second, the inference engine, is software that acts as a generalized problem solver. It is designed to perform simple reasoning processes through a set of rules created by the knowledge engineer. The inference engine can accept problem statements from a user and, using the rule structure provided, attempt to derive a solution. It can assemble needed information about the problem from data provided by
the user, then explain all of this to the user. The third part of the expert system is the stored expertise. This usually consists of a set of rules developed by the expert. Even though this simple method appears limiting, when hundreds of rules are put together the approach is highly effective.

Dairymen can provide data from a database, such as Dairy Herd Improvement (DHI), to an expert system. The system begins the reasoning process that might be used by an expert. It could categorize those animals for management actions, that is, those to be removed from the herd. The expert system programs the computer to be objective when determining which cows are or are not making a profit. With the computer we can process information quickly and increase accuracy in data transfer. With little extra effort on the part of the dairy farmer, the computer can help determine when a cow should be removed from the herd.

The purpose of this study was to develop and assess a system for culling dairy cattle. Expert systems were chosen as the programming environment because of their flexibility in use of rules of thumb and other knowledge that is helpful in making the culling decision.

This study involved primarily small-sized to medium-sized herds where the manager had knowledge of each dairy cow on an individual basis. This provided the opportunity to compare suggestions made by the computer with actual decisions made by the manager.
The objectives of this study were the following:

1. Identify from the literature management variables that need to be considered in development of an expert system.

2. Become familiar with at least two different programming tools, referred to as expert system shells. Identify which system has the logic that would develop rules which would reach the same decision as an expert dairyman.

3. Develop the knowledge base or rules for an expert system based on the findings of objectives one and two.

4. Run the expert system program using records from existing herds, in order to evaluate the performance of the rules and the output from the program.

5. Identify a group of dairies that could implement the expert system. Input data from these dairies and run the program to test if genetic and phenotypic production increases could be accelerated using an expert system.

Dairy management and the computer industry have unique definitions for many words and phrases. In the following discussion, background in computers is presumed. One source of information available that could help provide that background is A Guide to Expert Systems by Waterman (65).
REVIEW OF LITERATURE

Culling Dairy Cows

Cows should be culled based on profitability. This prompts the question "Is the cow making the dairyman money today?" To assess that question, some measures of production are needed. One measure used has been relative value percent within the herd, expressed as a percent of deviation from herd mates (70). Usually those animals evaluated for voluntary culling will appear in the bottom one-third of the list.

Production is not the only factor (28) that needs to be considered. We should also evaluate reproductive performance. The more days that a cow is in production the greater her lifetime production and profitability. Excessively long dry periods due to poor conception rates and/or extended days open are not profitable. Days open is a good indicator of reproductive efficiency. It can help dairymen to identify those cows who have problems that will extend their lactation and result in low production or extended dry periods.

Mastitis is also of concern to dairy managers. The average linear score for somatic cell counts is an indication of the level of infection in the herd. Cows that have linear scores greater than four are often candidates for culling (23). Cows that have high somatic cell counts
have reduced milk yields and are a source of infection for other cows in the herd.

The decision as to which cows are to be removed from the herd has a more pronounced effect on profits than most other decisions made by the dairyman (71). The number of cows culled can have a positive impact on the rolling herd average. Somatic cell concentrations in bulk milk, average days open, and average days dry in the herd can all be changed in a positive direction through proper culling of cows.

The number of cows leaving the herd for involuntary reasons is critical. Large numbers of cows that are culled for involuntary reasons restrict the number of cows that can be removed for voluntary reasons. The dairyman can exercise little choice as to which cows are removed for involuntary reasons. Most of those animals will have been affected by earlier management decisions. These decisions place them in jeopardy of being culled (70). If too many of the cows are in this category, the manager needs to evaluate other areas, such as reproductive status, herd health management, mastitis control and overall care of the animal with the objective of reducing rates of involuntary culling.

The secondary problem of involuntary removal (37) is that it usually involves animals of higher genetic merit that are producing at or above the herd average. This reduces the amount of genetic progress that can be made in the herd.
Williams and Ward (69) found individual records were useful when culling decisions were made. Producers who used DHI records received a cull list based on production parameters and the relative position of animals within the herd. Other information used by dairymen include: health records, reproductive records and the general knowledge of the herdsman. All of this information was used in making the management decision. This was adequate in the past when herd sizes were small. Information would be recorded and details were available from the dairyman's or herdsman's memory. The dairyman would use that information to identify cows that had serious health problems. Dairymen would also identify animals with serious physical defects that affect future productivity such as feet and leg problems, pendulous udders or injured teats. Reproductive condition, pregnancy status or multiple services would be evaluated. Occasionally a herdsman or dairyman would cull an animal simply on disposition. These animals posed safety problems or reduced the satisfaction of the milkers and others who worked with them.

All of these factors were weighed against the producing ability of the animal. Other important factors involved in reaching a decision to cull were the age of the cow and the availability of replacement heifers.

Rogers et al. (45) demonstrated that those animals removed for involuntary reasons had higher estimated producing abilities (EPA) than those animals removed for
voluntary reasons. In their study, reproductive failure surpassed mastitis as the most common reason associated with involuntary culling.

Rogers et al. (46) showed that involuntary culling resulted in losses due to reduced carcass value, idle facilities for producing milk and associated health costs. In another study, (48) they showed that when involuntary culling rates were decreased voluntary rates increased. There was little change in overall cull rates. Specifically the study indicated that by reducing involuntary culling by just one percent, net revenue would increase between $750 to $900 per year in a 100-cow herd.

Martin et al. (34) found that the rate of culling increased three percent per each year of age. Quite often the reason for removal was associated with low milk production. There were often indirect reasons but the events occurred months or years before the culling date. The factors responsible were not easily identified and tracked over the life of the animal. The study showed that diseases observed by the farmer but not seen or treated by a veterinarian were important to the culling decision. Assisting in delivery of calves at the time of parturition is an example of one factor that increased the risk of culling.

Dentine et al. (14) showed that levels of culling and reasons for culling differed between registered and grade cows in the same herd. This probably occurred because of
the differences in management emphasis. Owners purposefully increased the percent of registered cattle, thus placing more culling pressure on grade cows.

The culling decision comes down to two important questions. First, will it pay to replace this cow with a higher producing animal? Secondly, will it pay to remove this cow without replacing her? If heifers are raised on the dairy then excess heifers can be sold at greater profit than can cull cows. These decisions can usually be based in economic terms with a herd break even level.

**Early Removal of Lactating Cows Due to Health Disorders**

Health disorders are costly to dairymen. The areas of reproductive and udder health are the most extensive, but losses have also been noted from the digestive and general health areas. Major health problems that impact culling include incidence of mastitis, breeding trouble, difficulty at calving and repeated cases of milk fever or ketosis.

Erb and Martin (20) found that the distribution of diseases per lactation was clustered. Animals were at greater risk early in their lactations from reproductive and udder problems. They suggested that diseases occurred together in the lactation more often than expected. The stress created by one health problem could cause other problems to develop to clinical levels.

Milian-Suaizo et al. (38) suggest that the most common reasons for removal of animals from the herd were low milk
production, reproductive problems and problems associated with the udder. Culling for any of these reasons could occur throughout the lactation. However, culling for poor reproduction was usually between day 240 and day 360. These animals were bred late or had not conceived and were approaching the normal dry-off period. These researchers observed cows diagnosed as downer cows, which included cows with milk fever, ketosis or other diseases that can cause the animal to lose mobility. They found that downer cows also having clinical mastitis or teat problems are two to three and a half times more likely to be culled. Those cows that were diagnosed with diseases were often culled within 30 days of the diagnosis. Other cows culled shortly after diagnosis include those with problems such as displaced abomasums or feet and leg problems. Accidents occurred sporadically across the lactation and did not appear to be important reasons for culling.

Dohoo et al. (15) suggest that dairymen should know the frequency of a disease and the effects of the disease. This knowledge will help dairymen manage their herds to eliminate the economic impact and minimize the loss of production from the most frequently occurring diseases. Diseases can impact production efficiency by reducing the level of milk production, reproductive performance and life span of the animal.

Information on the timing of culling showed many animals culled at the beginning of the lactation (38). This
is due to the increased frequency of diseases associated with parturition. Deaths also commonly occurred within the first 30 days of lactation. The major cause of death was related to udder problems. Animals diagnosed with the disorders of dystocia, retained placenta, metritis, mastitis or cystic ovaries were more likely to be culled in the same lactation.

Shanks et al. (56) suggest that it is useful to determine when the disease occurs in reference to the calving date. They reported that about 20 percent of the health costs occur within the first 10 percent of the lactation.

Dohoo et al. (15) found higher incidence rates of mastitis and reproductive tract infections in situations where cases were self-diagnosed by the dairy farmer. This indicated that many cases of diseases are self-diagnosed and treated without the knowledge of professionals such as veterinarians. They also indicate that in most cases mastitis and reproductive tract infections occurred early in the lactation period, varying from seven days up to as late as 200 days.

Rogers and McDaniel (44) explored the usefulness of type-traits in eliminating or reducing specific diseases. They found that some type traits were correlated with problems such as infertility, poor udders, slow milkers, and poor disposition. Changes in the udder depth have some influence on reducing the involuntary culling levels
associated with these diseases. They found that only udder and locomotive traits have been consistently related to culling in commercial cattle, primarily because of recording problems.

Oltenacu et al. (41) suggested that primiparous cows with health problems were at a greater risk of being culled than multiparous cows with similar health problems, due to the pressure exerted by the dairyman. Culling in the herds they studied showed that animals thought to have problems were two to five times as likely to be culled as those classified as healthy animals.

Erb et al. (18) suggested through path analysis that some events in the life of the animal increased the risk of culling in the future. These researchers found that heifers who were older when they calved were more likely to have retained placentas and mastitis. Heifers that had high estimated transmitting abilities (ETA) also had high yield and a decreased risk of clinical mastitis. Those heifers that had cases of dystocia had an increased risk of retained placenta and metritis. Dystocia in heifers also increased the risk of being culled from the herd and increased the delay to first service by seven days. Dystocia, therefore, could have direct as well as indirect effects that accumulated and caused a heifer to be at increased risk. It not only was a precursor to reproductive diseases and poor breeding performance but also culling. Retained placenta
had indirect effects which were usually exhibited through cases of metritis.

Strandberg and Shook (60) reviewed breeding programs that considered mastitis. They found breeding programs that ignored mastitis had genetic increases in milk production and fat levels. They suggested that direct selection against clinical mastitis in the U.S. is an unrealistic goal. They did suggest that indirect selection was a possibility and could be nearly as effective in herds that use somatic cell counts.

In another study Erb et al. (18) found that heifers with clinical mastitis were 5.2 times more apt to leave the herd than heifers without the disease. Farmers were more forgiving of first lactation animals with low production than they were with animals which failed to conceive at first service. Multiparous cows diagnosed as having milk fever were two to six times more likely to exhibit cases of dystocia, retained placenta and metritis. Cows with milk fever exhibited indirect association with poor reproductive performance and an increase risk of being culled from the herd. Even though treatment of milk fever with a bottle of calcium was effective in eliminating the immediate effects, other hidden costs weren't removed as completely. Some of the indirect effects of milk fever were exhibited in poor breeding performance. This reduced the herd life of the animal and made milk fever a more costly disease than many producers realized.
Erb et al. (19) found that older cows with dystocia were at increased risk of having metritis and being culled. Cows having follicular ovarian cysts produced more milk, but they also had more days to first service and, therefore, to conception. They had poor conception at first service and were 1.5 times more likely to be culled.

Lin et al. (31) noted that cows with breeding problems such as days open, lowered conception rates, and higher number of services had greater economic losses and a higher probability of being culled. Dystocia, retained placenta, metritis and mastitis were positively correlated. Selection against any one of these traits would select against the other traits.

Hansen et al. (26) looked at labor requirements and health care expenses for cows that were selected specifically for higher yields. They found a higher labor and health care cost for animals in the high production group. Shanks et al. (56), in contrast, found that health costs did not differ greatly in the lowest and highest production groups. Both of these groups had higher health costs than the middle group studied.

**Culling as Related to Reproduction**

High yield, or the factors that are involved in high yield, have a depressing effect on cow fertility. This problem can be reduced by good management practices. Currently, with the economics involved in reproduction and
production, over-emphasis on fertility in a selection program is not warranted. Poor fertility needs to be taken care of through proper management.

Parturition, or the act of calving, is an extremely stressful event in the life of the cow, particularly heifers. It is normally a time for many adjustments in the animal as she tries to adjust to new diets and environments. There are many endocrine changes resulting from the initiation of lactation. Following parturition the cow's uterus must go through a normal involution process and the ovaries start the cyclical process of the cycle again.

Complications at calving, such as retained placenta, milk fever, ketosis and others, lead to delays in the involution of the uterus and normal cycling. The dairyman's objectives should be to minimize the impact of factors which lower fertility and delay the animal's normal cycle in preparation for breeding. Breeding problems result in excessively long lactations and dry periods. Both are costly to dairymen and need to be avoided.

Reproductive problems are costly to dairymen and reduce profits (35,63). Dairymen need to take measures that will help improve the reproductive status of the herd. If average days open are greater than 120 days, reproductive problems could be the cause of involuntary culling.

Bailie (2) suggests that the interval to first service and the level of estrous detection are the parameters that govern days open and calving intervals. Both of these
impact the herd culling rate by failure or delay in conception.

The two most important segments of the reproductive program involve heat detection and conception rate (2). These can be measured by days open and services per conception. After removing the causes of abortion, days open is the most important indicator of reproductive efficiency (54). Most dairymen are managing for 90-110 days open which would translate into a 12.2 to a 12.8 month calving interval. Researchers (2,3) have enumerated three primary ways to reduce days open. First, by increasing the rate of heat detection. Second, by increasing the conception rate. Third, by reducing the time between calving and first breeding. Another common goal of dairymen is a conception rate of about 66 percent or no more than 1.5 services per conception.

Erb et al. (14) showed that previous production was not important in determining the occurrence of reproductive diseases. They found that disease affected not only the fertility level of the animal but also the production level of the animal in the current lactation.

Cobo-Abreu et al. (5) tried to determine a relationship between disease and productive ability of the animal over time. They recorded diseases in the University of Guelph herd and then tracked the productive life of individual animals. They were trying to find evidence of an association between the occurrence of disease and premature
culling or poor production. They tried to show that disease caused lower production which was the cause for removing the animal from the herd.

They (5) showed that cows that had cases of metritis had a delay of 1.8 months to conception. Cows with retained placentas had a delay of 1.14 months. Cows with cystic Graafian follicles had a delay of 1.3 months. Cows with ovarian hypofunction had a delay of 1.2 months. They concluded there was an association between culling and mastitis, metritis, retained placentas, and pneumonia. Therefore, these diseases are considered detrimental to production. This information adds to the reason for prevention of these diseases.

Erb et al. (19) noted a decline in breeding problems and reproductive disorders especially pyometrias, metritis and cysts for cows beyond 60 days in their lactation, implying that early management of these diseases could decrease the turnover rate later in the lactation.

O'Connor and Oltenacu (40) investigated the optimum dry period for dairy cows and found that requirements differ based on the age of the cow and the season when it calved. Economic gain can be obtained by drying off cows near the optimum dry period. Those at increased risk include first lactation cows, cows with longer days open and cows which freshened during the summer to fall period.

Schmidt (53) observed that as days open increased, the calving interval also increased. He also noted that
minimizing the culling percentages, especially those due to involuntary reasons, was also economically beneficial.

Goodger et al. (23, 24) noted that reproductive status largely determined the production and the profit of the dairy herd. Poor reproductive performance will extend the lactation beyond the normal producing period. This will decrease average daily milk yields and increase the number of days during the dry period for each cow. Losses related to reproduction can be calculated from four areas: (1) culling and replacement losses, (2) excessive breeding and medical costs, (3) milk production losses attributed to excess days that the cow is not pregnant and (4) losses attributable to fewer calves born.

Marsh et al. (33) found that maximum profits from a reproductive culling policy will come with less restrictive culling practices. The income over the variable cost decreased as the culling pressure was exerted back to the 165 days in milk breeding period. This occurred even though there was some positive benefit to the calving interval of the herd. The benefit of the shorter calving interval was far outweighed by the cost of the added reproductive culling. As these researchers found, the most profitable program was a more flexible culling pattern based on production and reproductive status of the cow. They found that it was worthwhile to breed cows up to 250 days after calving. It was important to continue culling the lowest producing cows without regard for their reproductive status.
These animals were culled because the calving interval that they would attain would be too long, not because they were infertile or could not reproduce. They concluded that regardless of the benefits to reducing calving interval, those herds that had reproductive problems could not stand the losses associated with the higher cull rates of a more restrictive program. A shorter calving interval, although desirable, must be achieved by improving management rather than by removing those cows that did not conceive on a regular basis.

**Voluntary Culling of Dairy Cattle**

Dairyman need to consider two questions in regard to variable costs. First, is the cow producing at a profitable level? Second, if the cow is not, what is the most economical culling point during her lactation? Cows which have milked <90 days should not be considered for culling under normal circumstances. They have not been milked long enough to accurately determine their production potential. A point when cows are covering all of their variable costs and can contribute to some of the fixed costs is what is termed "break-even point." The cow should remain in the herd as long as her production covers all of her variable costs (35). Any additional production from the cow helps offset the fixed costs of the herd. This point, if it can be identified or approximated, could help in the culling decision.
In most situations the ideal time to cull a cow from the milking string is when her income from daily production equals her variable costs. The optimum time to remove an animal when there is pressure from replacements is when her production does not cover the variable costs plus a portion of her fixed costs.

It is difficult to identify those cows when personal preferences creep in that affect the judgment of the herdsman or manager. Many researchers (8,10,12,22,37) have demonstrated that animals with high production in their first lactation have long or productive lives.

Williams et al. (68) studied the correlation between variable costs and dairy herd management practices. It was found that lower variable production costs were associated with herds having fewer days open and a younger age at first calving. They also found that herds with higher percent days in milk and lower percent cows leaving the herd had lower variable costs. Those cows leaving the herd are the measure of the culling rate. As a high percent of cows leave the herd, increasing numbers of replacements must be purchased. This increased replacement costs and the level of variable costs.

Increased days in milk were associated with lower variable production costs as well as higher production per cow. The more days cows are milking, the more they contribute income to offset the costs of the dry period.
Schmidt and Pritchard (52) attempted to determine if maximum production and economical production are the same under most conditions. Some of the variables that could decrease the profits per cow included: increased health costs, reduced reproductive efficiency, increased labor requirements and higher replacement costs. They found that income over feed costs increased as milk production increased at all milk and feed prices for large herd situations. They found that the replacement costs were influenced by several factors including: the cost to replace the cow, the cull cow price at the time of culling, and the percentage of animals culled. They compared three different percent of animals culled (30, 34, and 38 percent), all under conditions of high and low feed prices with milk price held constant at $12 per hundred pounds. Their studies showed that the lower cull rates resulted in greater income over feed and variable costs.

Congleton and King (11) tried to develop an algorithm to predict the effect of the culling decision on the net income obtained from the herd. They also tried to determine the best time to cull animals and a procedure that could be used on commercial dairy herds. They found that the culling decision could be based on a set of net present values.

Researchers (30, 63) have tried to identify those cows which need to be culled using an index. One of the hidden costs they noted of high levels of culling is that as older cows are culled to be replaced by heifers, herd averages can
drop by approximately 25 pounds for each 1 percent increase in culling. This is because the older cow is producing at a higher level than her replacement will be. In many herds culling is occurring at higher levels than is economical. Animals with potential problems need to be identified early in their lactation and then have those problems corrected with good management practices to help lower replacement rates in those herds.

Kuijpers (30) compared several models to help determine the time to remove animals from the herd. The predicted monthly return index was based on a cow’s predicted profitability during the remainder of the current lactation and the first six months of the next lactation. MaxAMR (maximum average monthly return index) determines the average monthly returns for the planning period including each future month in the present lactation period and up to ten months into the next lactation. It then ranks those cows based on the maximum average value. Culling based on the MaxAMR increased the returns from milk minus the feed costs by identifying the optimal time to cull. Most cows were culled using this method during the middle third of the calving interval when the average monthly return values were the lowest.

Congleton and Roberts (10) used cumulative income curves of dairy cows to help determine the optimum time to remove them from the herd. They found that first lactation heifers should be culled about 3 1/2 weeks before mature
cows. The difference could partly be explained because milk production levels in later lactation are approximately the same, due to the heifers' more persistent lactation. Variable costs are higher for heifers as they consume more feed per unit of milk produced than older cows trying to meet growth and maintenance requirements. They also require a slightly longer dry period.

With an increase in the price of milk of approximately 10 percent, it was profitable to delay the culling decision by approximately two weeks for first lactation animals according to Congelton and Roberts (10). A delay of slightly over one week for cows in later lactations attained the maximum income. They also found that cows having repeated cases of mastitis should be culled earlier. They concluded that deciding which cows to cull should be based on long term effects. The determination of when the animal should be culled will depend on additional considerations such as, the opportunities there are for disposal of the animal and the availability of a replacement.

Tigges et al. (62) studied the use of dairy herd variables as a means to predict lifetime profits. They found that significant contributors to profit were milk yield, levels of mastitis, milk fat test, and the number of freshenings. The single most important variable when predicting profits per day was the level of fat produced per day. This variable accounted for 69 percent of the
variation. Fat production per day considered both milk production and fat percent.

Congleton and King (12) found that the maximum turnover of animals in the herd will shorten the generation interval. It can contribute to genetic trends especially when high levels of genetic improvement are sought from sire selection. Many studies (8, 10, 11, 63, 65, 71) have indicated that the profit levels of the herd will increase as the herd life of the animal is extended. These researchers suggest that reducing the rate of culling would increase profits. Congleton's work (7, 8, 9) suggests that culling rates for voluntary purposes above three to eight percent decreased economic returns. This occurred when the replacement costs exceeded by 150% the value of the animals culled for beef purposes. When replacement heifer prices were near or even below the beef value, then higher cull rates could be used without affecting the profit level. The recommendation for dairies with average herd lives of approximately three lactations was that cows should be retained longer. This would increase annual net income for those herds. This would be the case assuming that the annual cost for health and labor did not increase more than $30 per year.

Faust et al. (21) demonstrated that with increasing levels of fat corrected milk, fertility levels declined. The three measurements that decreased as milk production increased were days open, average days to first service and services per conception.
Weller (66) found the same situation occurred in Israeli dairy cattle but concluded that some positive results will occur in selection for fertility. Costs were reduced by not breeding open cows that were identified as poor milk producers early in their lactations. A farmer has a similar situation each time some malady strikes an animal. He must decide if treatment of the disease or injury will return a profit, or if the alternative of removing that animal from the herd and replacing her would generate greater profits (63).

Rogers et al. (47) showed that when the difference between the replacement heifer cost and the value of the cull animal was approximately $550, the most profitable replacement rate was 25 percent each year. If the difference between the replacement cost and the cull cow value was $450, then the dairyman could increase the cull rate to 28 percent. If the difference in value increased to $650, then the profitable culling rate was decreased to approximately 23 percent. To summarize, every $100 increase in the difference between these values changed the most profitable culling rate by approximately 2 to 3 percent. They also noted that increasing involuntary or forced culling lowered the rates of culling for low production and lowered net revenues.

Culling for health and reproductive problems reduced herd profits. The reduction was due to increased replacement costs and lowered milk production from higher
yielding mature cows. Any culling in these situations is referred to as involuntary culling. Research (44) has shown there is an undesirable genetic relationship between milk yield and these reasons for involuntary culling. Rogers and McDaniel (46) investigated specific traits that might be selected to lower cull rates. They found that most type traits have little value in selection programs aimed at reducing the involuntary cull level in commercial dairy cattle. They noted in another study there is some relationship between udder depth and teat placement from the rear view in first lactation animals and longevity of the animal (47).

Madgwick and Goddard (32) studied longevity in Australian dairy cattle. They noted the difficulties in identifying those particular traits that are associated with longevity. Progress in those areas can best be made through non-genetic means.

Schmidt and Smith (51), when determining why dairymen use DHI and herd improvement programs, noted that most dairymen responded that monthly progress reports were the main reason for participation. They also noted that herds using DHI reports as guides for culling had lower average age at last calving, days to first service, calving intervals and higher services per cow. Those herds that used somatic cell information had lower ages at first and last calving, higher services per conception, and a higher percentage of cows with low somatic cell counts.
Dairymen who used the information had higher production per cow and above average performance levels for their herd. When identifying what the reasons were for using DHI, they found that approximately 44 percent of the dairymen surveyed used the information for culling unprofitable animals. When trying to identify the ways that these records were used for culling animals, it was noted that 79 percent used the completed records, 56 percent used breeding information, 53 percent used potential cull lists, and 51 percent used relative value. Fifty percent used the extrapolated ME record, and 39 percent used somatic cell count information. Dairymen also indicated that some of the information they had access to was unusable. Only one-third of those surveyed indicated that they had an insufficient amount of time or expertise to interpret their records.

In a study by Zweigbaum et al. (71) it was found that one of the highest contributing costs in production per cow was regular herd health care. This study tried to relate management and production differences to variations in profits among farms. They noted that heat detection had a major impact on profits. They found that by using an estrus detection aid they could reduce days open by eleven days which increased net income. They also noted that dairymen using a veterinarian for on going reproductive health programs, rather than just to treat problems, had an increase of 448 kilograms of milk which amounted to $152 in net cash income per cow.
Van Arendonk (63) showed that a decrease in involuntary cull level allowed for an increase in the voluntary cull rate resulting in a larger profit to farmers. He then concluded that dairymen should delay or eliminate any reasons for involuntary disposal to increase their profit levels. He referred to this as "functional stayability."

Keown (29) looked at the relationship between herd management practices and levels of milk and fat yield to determine the major reasons for culling animals. The two major reasons were low production and breeding problems, followed by mastitis and very distantly by feet and leg problems.

Rogers et al. (45) noted that culling for involuntary reasons is a major cost to dairy farmers. Reduced opportunity for those high yielding cows to stay in the herd and the increased cost to find replacements represent the major cost for premature culling. Early culling for health or management reasons included poor disposition, pendulous udders, slow milking speed, etc. Much of the culling was due to low yield that resulted from health problems that were not correlated in the dairyman's mind.

Congleton (6) compared culling cows on a projected income versus mature extrapolated milk production basis. He found that herd income levels increased by 4.3 to 4.8 percent over a 20 year period when using projected income methods.
Rogers et al. (46), while trying to determine the optimum culling levels, noted that the decision to cull was very sensitive to changes in replacement heifer prices. They also noted that the optimum average culling rate was about 25 percent, which led to a 47.8 month average herd life.

Congleton and King (11) showed that increasing the average cow productive life from 2.8 to 3.3 lactations increased profits. When beef prices increased there was reduced advantage to increase the productive life of the cow. The financial losses that were assumed by cows being culled for involuntary reasons included the loss due to lower production before removal. Other losses included: veterinary costs, costs due to idle production factors, such as the parlor, and lowered carcass value. Lower carcass value usually resulted from disease or injury. When looking at the distribution of involuntary culling across time, they noted that twenty percent of the cows involuntarily culled were removed within the first month after calving. Only four percent were removed within the last month before dry off. They recommended an optimum culling rate of 25 percent with the best combination of involuntary culling at 16.5 percent and voluntary culling at 8.6 percent. They also noted that many first lactation animals were culled. Therefore, second lactation cull rates were usually 50 percent lower, because those animals who lacked the ability to produce milk had already been removed from the herd. The
average time that animals were involuntarily removed from the herd was 168 days in lactation, where the average time for voluntary culling of animals was 263 days into lactation.

Rogers et al. (45) continued to study the effect of reducing involuntary levels and found that reducing the involuntary culling by 2.9 percent resulted in about a $22.00 increase in revenue per cow per year. This reduction was approximately a 20 percent decline in the level of involuntary culling. They noted that a 10 percent increase in milk yield corresponded with a proportional increase of 20 percent in the involuntary culling probability level. This demonstrates a very antagonistic relationship between production and involuntary culling. The increase in annualized income associated with reducing involuntary culling came primarily from less expenditure for replacements. Other benefits came from the decreased frequencies of low producing cows and extending the productive life of high yielding cows. Over half of the increase came from the combination of the latter two reasons, indicating that one of the major costs of involuntary culling is the forced reduction of the ability to intensely cull for voluntary reasons.

They concluded that culling for health and husbandry problems affected cull levels for milk yield. This in turn impacted the level of net income per cow. Management and breeding programs should be directed towards reducing the
level of involuntary culling. The average productive life of the animal in the herd may change little. This could happen when voluntary levels increase to compensate for the decrease in involuntary cull rates.

Spahr et al. (59) noted that although many models have been used to aid in the culling decision, many of these aids have been incomplete. They typically do not consider the value of a particular animal as a brood animal. They also ignore her age and health status. Seasonal needs for milk of the particular dairy market should also be considered.

**Expert Systems as a Management Tool**

The term artificial intelligence was first coined in a 1956 Dartmouth conference by John McCarthy (4). More than thirty years have passed and many people see this as an area of great promise. The field of artificial intelligence is very broad and quite diverse. Some of the areas of specialization include robotics, natural language understanding, speech recognition, vision, computer aided instruction, learning, and expert problem solving. The area of intelligent artifacts related to the organization, interpretation and analysis of knowledge. This is commonly referred to as expert systems and is probably the most common application of artificial intelligence.

Expert systems offer a structured approach to knowledge representation. Techniques are used to represent data in ways that generate inferences that cannot be programmed
through algorithms (64). When properly written, an expert system helps guide users through large amounts of data with the strategies and rules of experts captured in the system. The data intensive nature of dairying provides numerous opportunities for expert systems. These systems can assist in the evaluation of these data in controlling herd performance and in management of animals.

Expert systems development is a large task and elegant results are not to be expected in the short term. The use of computers for the management of large dairy herds is becoming increasingly important. Many researchers (51, 58, 60, 69) have investigated ways that this can be facilitated. These researchers were identifying ways that computers could help to diagnose health and estrous problems early in the lactation. This could help reduce the number of animals lost from culling. Currently some of the challenges that researchers are working on involve sensors. These will identify problems with conductivity in the milk, change in temperatures, pulse rate, and activity levels. The readings can be used to help diagnose health problems and for heat detection in large dairy herds.

This type of computer technology is advancing rapidly. Ten to fifteen years ago an expert system would cost around half a million dollars, even five years ago it would cost about $50,000. Companies have now separated the rules specific to the problem from the inferencing engine and the user interface. This package, called an expert system
shell, requires a programmer to enter only the rule structure to develop the system. At the present time many shells are available for under $500.

Two types of knowledge that are available to an expert system are declarative and heuristic knowledge. Declarative knowledge is facts about a subject, such as a cow, found in databases and managed using database software. Heuristic knowledge is knowledge that is typically involved in rules of thumb. An expert system offers a structured approach to representing that knowledge. It can be used in generating inferences that might not be programmed another way. These rules help guide the user to knowledge during a consultation with the expert system shell. The expert system must be flexible although structured. Often expert systems can be useful for tasks that are ill structured and involve the making of decisions with incomplete data.

Initially when expert systems were developed (36) and programmed through source code the inference engine and the rule base were intricately intertwined. As programmers continued to develop these expert systems they began to realize that the rules and the mechanisms for applying them could be separated. Thus, the expert system shell was developed. The expert system shell was an empty expert system. It had the inference engine with the ability to develop user interfaces but lacked the rules that were necessary. Once the expertise in a domain area was encoded and became a part with the expert system shell, then a full
fledged expert system was formed. Some shells require rules to be entered in a specific well defined order. Others can be induced from a table of examples. The goal is to make it as easy as possible to get the knowledge into the system. Many of the newer shells make entering the knowledge easy enough that a specially trained knowledge engineer is not needed.

The expert system shell has the potential to distribute an expert's knowledge (64) to a much wider audience. Knowledge from the experts can be available at times that would be inconvenient otherwise. Three common components of an expert system include: the user interface, the knowledge base and the inference engine. The user interface asks questions and allows observations to be entered. It searches for data in databases and when necessary asks the user for added information. It reviews the logic that the computer might be using in solving a problem. In many shells, the user interface has a very natural English language method of interacting with the user. The information obtained from the expert, called the "knowledge base," is the second and most important part. The third component of the expert system is the inference engine. It selects the rules to use, accesses and executes those rules and determines when an acceptable solution is found. Many times this process is called a rule interpreter.

Expert systems are knowledge based programs that emulate the thought of the expert to solve significant
problems in a very specific area of expertise. These computer programs use knowledge and entrance procedures to solve problems which normally require the help of an expert to produce the optimum solution. They mimic behavior of the human experts and are somewhat restricted to a very specialized area of knowledge.

Expert systems derive their problem solving power from a new approach to computer programming (27). Many problems cannot be solved efficiently through algorithms that are currently available from conventional programming methods. When some information is missing these conventional programs fail. Instead of being programmed to follow step by step procedures the expert system follows a few general procedures to find the proper solution. Often these are called rules of thumb, models, facts, and other general knowledge that will help to solve a problem. To solve a particular problem the computer uses facts about the problem supplied by the user. It combines this information with information already contained in the knowledge base. Through general problem solving procedures the expert system can find and apply a particular solution.

These systems are inherently designed as user friendly and they are somewhat evolutionary. This means they must be kept up to date or they can rapidly lose their effectiveness and become inapplicable.

Expert systems are more tolerant of errors and imperfect knowledge than conventional programs (36). They
can access alternative methods to answer questions where missing data might occur. In expert systems the knowledge itself is maintained separate from the general reasoning mechanism. These systems are usually developed on an incremental basis rather than being fully implemented at one time.

The reasoning mechanism in an expert system is called the inference engine. This part of the program is used for a variety of applications not simply the specific knowledge area being developed. It can draw conclusions based on data. An inference engine provides reasoning power using strategies borrowed from former logic and rule analysis. The inference engine uses search patterns to find its way through a maze of possible paths to arrive at the best possible solution. An inference engine is designed to solve a problem by applying the expertise that is coded into the system to the data of the specific problem. The expertise has to be encoded in such a way that it is accessible to the inference engine. Usually the expertise gets encoded in the rules.

The process by which an expert system is constructed involves a series of steps (4). The first step is to identify the problem. The problem must be such that an expert could solve it. It must be specific enough, not too broad. It should be a problem that can be handled best with a rule based system rather than conventional programming. The second step is acquiring available knowledge that is
associated with this problem. This acquisition can be primarily through a search of the literature (56). Dialogue with people who have better than average ability to solve this problem, often called experts, is another source. The developer (27) must decide on which method to represent the knowledge as he acquires it. The next step involves the actual programming of the expert system using either an artificial intelligence language or expert system shell.

Knowledge from experience is called heuristics. It is this heuristic knowledge that gives the expert the edge in solving problems. Though this form of knowledge is simple, its power lies in the experiences obtained from solving problems. It is the combination of learned principles and laws along with heuristic rules that gives the expert this significant capability.

The rule base in an expert system is the result of encoding the expertise. It may take several rules to express the knowledge used by a human expert. This knowledge base encodes knowledge that is often composed of feelings, rules of thumb, hunches, unconscious or subconscious processes. An expert system must have knowledge represented in clear unambiguous rules that are precise, complete, and consistent. Rules in the expert system attempt to summarize the knowledge of one or more highly qualified individuals known as "experts." The rules are structured as conditional if-then logical decisions. They may number from a few to several thousand.
The rules are conditional statement of two parts. The first part, called the premise, is composed of one or more if clauses establishing conditions that must apply if a second part is to be acted upon. The second part, called the conclusion, is composed of one or more then clauses. The concluding clauses could include assigning new variables to fields, storing records in a database, consulting another rule set, or changing the value and reentering it into a database. The conclusion is reached only if the premise is true. Sometimes rules are not obvious in a knowledge base, yet often it is the indirect rules which, when combined, lead to a conclusion.

Knowledge representation is the description of the acquired facts within reasoning strategy to solve the problems (64). There are four types of knowledge that are often important in an expert system. The first, object knowledge, consists of various facts such as physical descriptions, categories, or classifications about objects such as persons, places, or things. Second, event knowledge, consists of facts or descriptions about actions or events that have occurred or will take place. They include a cause and effect relationship. Third, performance knowledge describes behaviors. Fourth, metaknowledge is what we know about the limits and contents of our knowledge. It is often intuitive and very difficult to quantify. Experience is the knowledge gained from solving a problem by experimentation.
Some individuals compile knowledge into abstract and theoretical patterns which is called deep knowledge. Others compile their knowledge as a result of many practical experiences which is called surface knowledge. Expertise consists of a large amount of this compiled knowledge. A rule of thumb or other simplification tool that reduces or limits the search with large problems is considered heuristic. Heuristics do not guarantee correct solutions. Experts are people who are good at sorting through irrelevant information to focus on details important to the problem at hand.

Heuristic rules, which most knowledge bases consist of, are rules that are written to duplicate the heuristic that an expert might use to solve a problem (4). One of the problems involved in creating the knowledge system is converting an expert's heuristics knowledge into rules.

Ideally, the inference engine or expert system should reach a decision through the same process used by humans(4). It would consult any known information, collect new information from other sources, and reason through this information to reach a conclusion. The inference engine has the ability to access fields of a database. It also has the capability to ask questions to fill in gaps of information that are missing. The inference engine is the thinking component which gives solutions to posed questions that are prompted by the information stored in the knowledge base. If sufficient information is not available, then it has the
to determine if the rule is correct. It backs up to the if clauses of the rule and tries to determine if they are correct. This in turn leads the system to consider other rules that would confirm the if clauses. In this way the system backs into its rules. This procedure usually involves a smaller number of possible outcomes. It is goal driven. The other approach is a forward chaining process which takes the information and proceeds forward through the knowledge base looking for a valid path. Usually the number of outcomes is fairly large and this particular process is data driven.

The second strategy that the inference engine uses in directing its process is to control the depth of the search. In doing this the system takes every opportunity to produce a subgoal before searching for broad based and general information.

The inference engine can accept a problem statement from the user, then use reasoning knowledge about the problem area in attempting to derive a solution (64). It can further gather needed specific information during the consultation and explain why it needs this added information. It then presents the solution to the user and explains its line of reasoning used in reaching this solution. The recommendations of the system are based upon inputs from the user and results of if-then axioms and rules of inference derived from the expert. The input process for the user is ideally simple and easy to use. The user
establishes the local conditions and limitations of interest of the system.

The user interface performs the interactions between the user and the computer. It accepts requests from the user and comprises the channel through which the responses are given. If the expert system is not user friendly, all the power of the inference engine and all the expertise in the rule base are inaccessible. A well programmed interface asks the user many questions that can be easily answered. The goal of the user interface is that the user has easy access to the system.

The knowledge subsystem consists of several types of knowledge. The reasoning knowledge of experts is represented as rules in the set of rules corresponding to the stored expertise of the expert system shell. When the knowledge system is integrated in an environment with the inference engine it can include information from large databases such as DHI. Information can also be imported from spreadsheets, models, forms, text files, external files, and others. This allows flexibility to the knowledge engineer in providing ways that the computer can be a medium for dialogue between the end user and the expert.

Bulky data with many inner relationships presented over a short period can overload the user. Data become useful information when the relationships between items are cohesive.
Some of the advantages (4) of expert systems include the following: first, it can help fill in the gap when expert advice is needed but none is available, for example, if someone is sick, on vacation, or retired; second, it is effective by being on call 24 hours a day, 7 days a week; third, the process of organizing and managing the expertise is highly instructive and provides an opportunity to study an area in detail.

One of the disadvantages of expert systems (27) is that construction of expert systems is a large and costly undertaking involving numerous man hours and large capital investments. Also, most expert systems are fairly ignorant in that they can not learn from experiences.

Often in the development process the expert does not know why he makes a particular analysis and derives a particular solution. In the process he will note that his intuition as well as rules of thumb and experience all come to play in the process.

Quantity and quality of knowledge possessed by a person or a computer can be judged by the variety of situations in which the person or program can obtain successful results (36). Small knowledge systems are systems containing fewer than 500 rules. They are designed to help individuals solve difficult analysis in decision making tasks without aspiring to be the equivalent of any human experts.

Surface knowledge, experimental or heuristic knowledge is that knowledge acquired from experience and is used to
solve practical problems. Surface knowledge usually involves specific facts and theories about a particular area or task.

Typically the development of an expert system is performed iteratively (64). The prototype is built first then the knowledge base is expanded upon and modified until the system reaches expert performance levels. When developing expert systems it is important that large problems be identified and programmed into smaller sub-problems to have efficient utilization of the system.

To identify applications that can fit into the area of expert systems six criteria need to be assessed (4). Number one, the problem solution requires reasoning. This involves the use of judgement, expertise, and specialized knowledge which took some human a period of years to acquire. Number two, the problem area must be self contained and the boundaries well defined. Number three, the problem usually involves the application of more variables than an average human can retain in memory at one time. Using expert systems to solve simpler problems may not be cost effective and hard problems may be beyond the capability of present systems. Number four, knowledge or an expert must be available to be debriefed. Number five, the knowledge has value but cannot be readily obtained by people who need it to solve problems. Factors that cause information to be unavailable include: death, retirement of the expert, or the prohibitive cost to bring the expert to a particular
location. Number six, there is a measurable pay off in accuracy, timeliness, consistency, and the quality of the decision making of the expert system developed.

Usually complex problems do not have best solutions, they have a possibility of many. The function of an expert system is to select one best solution out of perhaps thousands of different options. The expert system must be narrowly focused to arrive at the proper solution.

As the complexity or the scope of the expert system increases, the number of possible solutions increases. This makes the expert system much more complex, more difficult to develop and many times more difficult to maintain. This adds to the likelihood that it will not be maintained properly and that the correct solution to the particular problem will not be found. The problem that is being analyzed must be worth solving.

An example of an expert system (67) is the one developed to capture the expertise of Aldo Cimino. He worked for Campbell Soup Company for thirty years and at age sixty-three was nearing retirement. He helped to insure that all of the company's hydrostatic sterilizers operated correctly. This particular expert system contained about thirty years of Cimino's experience and about fifty percent of the known operational facts about the hydrostatic sterilizers. It was encapsulated in a hundred and fifty-one rules. The cost of this particular expert system was approximately $65,000. Campbell Soup Company estimated the
first time that the hydrostatic sterilizers were able to operate effectively in Cimino's absence, the cost was recovered.

Some others (16, 27, 39, 43, 54, 57, 61, 67) that have been developed in Agriculture include Plants/ds, developed at the University of Illinois, for diagnosis of soybean diseases. Another is Comax which was developed by the USDA to help in understanding inputs for cotton crops. An example of a large expert system is one called Expert that was written at the University of Maryland. It contains a knowledge base with over six-hundred and seventy million combinations of disease possibilities.

One of the reasons that so many expert systems are being developed currently is that the decreasing price for computers has allowed many more people to have access to hardware. The second is that the expert system shells have made it much easier to develop the expert systems. Until recently, expert systems have been strictly used on big computers with big programs and exotic computer languages.

Advances in the computer microprocessor have made expert systems economically feasible. Micro-chips and inexpensive memory have both been necessary for expert systems to operate.

Many vendors now offer expert system shells. When installed on a general purpose personal computer they allow expert systems to be developed and delivered using simple rules. This eliminates the need for a programmer. Most
expert systems shells also contain a natural language interface. It provides for persons with limited computer experience to be able to interact with the expert system to obtain the information desired.

One of the steps involved with development of the expert system is the characteristics analysis of the problem (4). This includes a preliminary assessment which involves learning the nature of the problem and its boundaries. This step is critical to help identify which type of software and hardware can be used to develop the expert system. It also impacts the methods that need to be used in testing and deployment of such systems.

The next step is tool selection. One needs to identify whether a programming language should be used or if an expert system shell would be more effective. An important consideration in selecting the tools should be price. Hardware, expert system shells and software can be expensive, costing up to thousands of dollars. Training expenses for operation or programming can be high.

The next step in the development of the expert system should be the start of a prototype. The knowledge base and the inference or logic processing mechanisms should be developed to a point where the system can be demonstrated to other experts and selected users. This begins the process of refinement. The demonstration should be critically examined and procedures should be followed to determine accuracy, completeness, and user friendliness. This process
can be expected to result in many revisions, as well as additions and deletions and can take a considerable amount of time.

The next step in development includes field testing. It is necessary to verify accuracy as well as usefulness. One of the ways this can be done is to use the current method as a comparison and then document the action. Without interference, have the expert system analyze the same information to see what answers it produces. A well designed, accurate system would achieve nearly a hundred percent agreement with the human practitioners.

At some point in the development process, those involved need to look at the potential benefits of the expert system application (37). The benefits must be weighed against the cost associated with developing and maintaining that software. This also helps to determine if the project will be feasible and even if the expert system is the best method to address that particular problem.

When developing expert systems (4), it is helpful to group information that has some logical basis to the way the rules are selected. These groups help the developer as well as the user to track the thinking that has gone into the expert system. The use of these frames helps to organize the knowledge base into component or sub-problems. This offers a more modular structure to the development process. It lends itself to the development process in a way that
each different mode or module can be developed independently of the entire project.

Developing an initial prototype has some distinct advantages causing those involved to deal with the complexity of the problem. These prototypes usually do not consist of a full set of rules and do not have all the user friendly interfaces that will be in the final version.

The Dairy Herd Improvement system is continually being used as an important part of the dairy management process (52,69,71). The reports are very sophisticated. As the needs of the dairyman increase the database becomes larger and more difficult to follow. They represent a more formidable challenge to interpret.

All the dairy record processing centers have investigated the dairyman's need to access those databases. They are developing programs for accessing and capturing data and reports from their farm. These databases are not only large but very dynamic in that they change regularly and must be continually monitored on a herd basis.

The expert system (60) can provide a potential method to help users examine these databases and make correct decisions. New expert systems provide a way that information from large databases can be moved directly into the expert system. This reduces the chance of error through data manipulation. It reduces the time that the manager must spend inputting information to the expert system.
The main reasons that dairy farmers indicated for not using their DHI records more completely was a lack of time and a lack of understanding about the interpretation of the management reports.

Expert systems represent a fifth generation programming language (64). Each generation represents one step farther from the actual machine language which computers use toward the everyday communication type of language which humans use.

These tools have been shown to be effective decision makers for problems which require heuristic knowledge. It is tireless, it is always available for use. Expert systems will probably replace many other kinds of decision making software because of their basic user friendliness. They also provide greater utility in situations where incomplete data are provided.
Program Development and Rule Construction

Computers have been used to help dairymen make culling decisions. Software has been developed using conventional algorithms. However, the information used has often been incomplete. In an attempt to overcome these limitations, the process of developing software using the expert systems approach was begun.

Conventional programming languages such as Fortran or Cobol have been used to develop computer aids for culling. These languages have limitations that hinder the use of rules of thumb. Expert system languages allow flexibility in their programming to tolerate incomplete information and hunches. To be complete, expert systems must have a set of rules programmed and available for reckoning.

Expert system shells have been developed which provide the programming needed to process the knowledge base. Using one of these shells limits programming requirements to the construction of the knowledge base. Two shells were tested in the preliminary stages of this study in order to determine if one would be better than the other in solving the culling problem. VP Expert and Super Expert were selected because they claimed to be powerful enough for this problem. Both systems were reasonably priced (less than $300 when purchased). Each system had a different method
for knowledge representation and a different method for control of the inference engine.

The task of culling dairy cows was defined as clearly as possible. The purpose of the computer program was to aid the dairyman with interpretation of the information that is normally stored in DHI individual cow records. The system was developed to aid the dairyman in culling cows at the proper time for his dairy situation.

Input variables to be included in the guide were selected on the basis of three criteria: (1) was it economically important to the profit level of that dairy cow? (2) was that piece of information normally available to the dairyman? (3) would the information on that management area be of a nature that the dairyman could change some management scheme to improve it?

Many health problems can reduce the level of milk production and the length of herd life of cows (18,34). These variables have varying degrees of impact on the animal. Displaced abomasum, mastitis and teat injuries had the greatest impact. Feet and leg problems and metabolic problems are usually more tolerable. The health list in Table 1 is a summary sheet of those diseases and conditions abstracted from the health management program used by DHI Provo.
### TABLE 1. Health management identification list.

#### REPRODUCTIVE
- Abort- (Unk, Bruc, IBR, Lepto, Mech, Twins)
- C-Section
- Calv-Down [Paralyzed while calving]
- Cystic-Ovry
- Hard-Birth
- Metritis
- Pyometra
- Retain-Plac [Retained Placenta]
- Stillbirth
- Adheson-(Ut, Ov, BC) [Uterus, Oviduct, Birth Canal]
- Uter-Infect [Infected Uterus]

#### DIGESTIVE
- Bloat
- Diarrhea
- Disp-Abom -(L, R) [Left, Right]
- Hardware
- Indigestion
- Ketosis
- Milk-Fever

#### MAMMARY
- Blind-Qu- (LF, RF, RR, LR) [Designate quarter - L=left R=right F=front R=rear]
- Broken-Uddr
- Cut-Teat-(LF, RF, RR, LR)
- Edema
- Hard-milker
- Mastitis-(LF, RF, RR, LR)
- Mast-(coryn, E Coli, Staph, Strep, Other)
  [A second line with the same date could identify type of organism after quarter designation.]

#### GENERAL
- FootRot- (LF, RF, RR, LR) [Left front, Right front, etc]
- Lameness-(LF, RF, RR, LR)
- Sole-Abscess
- Stifled
- Swoll-hock [Swollen hock]
- Abscess
- Downer-cow
- Parasites
- Nervous-Dis
- Pink-eye
- Pneumonia
- Poison
- Respiratory
- Ringworm
- Injury.

() = Letters inside parenthesis indicate alternatives to identify location or type.

[] = Provides explanation of list.
The overall objectives of this project were threefold. First develop an expert system for culling management in dairy herds. The system would need to interface with DHI records to obtain most of the important information. Then, through a user friendly interface obtain any further information to help in reaching the solution. The second objective was to determine if the expert system could mimic the decision making process used by dairymen. Finally, determine if expert systems were beneficial in the interpretation of dairy herd improvement records.

Possible interactions were recorded between the variables and compiled in a table using a popular spreadsheet program. These variables were identified in the literature review and summarized in Table 2. The variables had specific rules developed to help identify cows with either health, reproductive or production differences used in the culling decision.

The table was then used by the Expert System shell to create a prototype of the knowledge base. This was accomplished through the use of an induction ability from within the shell that added the correct syntax to develop the rules. The induction ability greatly reduced the time to program the rules.

The expert system included a text editor for use in correcting errors in the programming of the rules. This text editor was labeled a rule editor. It was used to modify and edit the rules contained in the knowledge base.
TABLE 2. Culling decision variables listed by knowledge block and researcher.

<table>
<thead>
<tr>
<th>Block</th>
<th>Variable</th>
<th>Researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reproduction</td>
<td>Days in milk</td>
<td>Milian-Suazo (38)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rogers et al. (46)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dentine et al. (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marsh et al. (33)</td>
</tr>
<tr>
<td></td>
<td>Abortion</td>
<td>Lin et al. (31)</td>
</tr>
<tr>
<td></td>
<td>Service per conception</td>
<td>Baillie (2)</td>
</tr>
<tr>
<td></td>
<td>Uterine infections</td>
<td>Shanks et al. (56)</td>
</tr>
<tr>
<td></td>
<td>Reproductive disorders</td>
<td>Martin (34)</td>
</tr>
<tr>
<td></td>
<td>General</td>
<td>Hill (29)</td>
</tr>
<tr>
<td></td>
<td>Displaced Abomasums</td>
<td>Dohoo et al. (15)</td>
</tr>
<tr>
<td></td>
<td>Mastitis</td>
<td>O'Connor et al. (40)</td>
</tr>
<tr>
<td></td>
<td>Udder Support, Type</td>
<td>Erb et al. (18, 19)</td>
</tr>
<tr>
<td></td>
<td>Feet and Leg Problems</td>
<td>Cobo-Abreu et al. (5)</td>
</tr>
<tr>
<td></td>
<td>Fat Corrected Milk</td>
<td>Erb et al. (20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strandberg et al. (60)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Goodger et al. (23)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rogers et al. (47)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oltencu et al. (41)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Schmidt et al. (52)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Congelton et al. (11)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tigges et al. (62)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Keown (29)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Williams et al. (68)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kuipers (30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kuipers et al. (69)</td>
</tr>
</tbody>
</table>

When the table of criteria was induced the factors contained in the "IF" statements identified points about a relationship. The premise and conclusions for each rule were programmed into the "IF" and "THEN" part of the knowledge base. Rules were set forth in an order which provided for sequential treatment making use of the premise encountered then following the conclusion prescribed. Example: Rule-IF the cow under consideration has no reproduction problem, THEN the conclusion is made from this rule that the animal is reproductively sound. Facts must be entered by the user or determined by the system from
compilation of other facts. These facts can be entered as numbers, text or options on a menu.

Once the prototype was developed, some example problems from DHI herds were selected. The animals selected had been culled from the herd. Data from those individual cow sheets were entered into the computer to analyze how well the initial expert system evaluated each cow. Through this part of the development process, input and output problems were noted. Observations were made that could stream-line the interpretation of output from the expert system. Information that could be grouped into modules was also identified.

The user interface was then programmed for the prototype. Undergraduate students from the dairy production course were allowed to interact with the system and record their input along with the systems output. Supervision of students helped in the discovery of some assumptions that created gaps in the knowledge base. These gaps in the knowledge base were bridged to complete the rules.

As the knowledge base was developed, efforts were taken to make it logical and easily maintained. In some cases individual rules became excessively large and were reduced into several smaller rules. The primary purpose of the system at this point was to help develop an outline of the knowledge base. This also aided in better understanding the task at hand.
The VP-Expert program was chosen for further use as it allowed the greatest amount of flexibility and ease of programming. The shell chosen was one written by Paperback Software. The main criteria for choosing this particular program was its friendly user interface. It had the capacity to do inductions from tables rather than examples, which aided in the formation of rules. Its runtime inference engine processed the data rapidly, which reduced overall time to evaluate the animals in question.

While developing the rules the literature provided many rules of thumb and points to be considered in evaluating each animal. Knowledge acquisition involves collecting and organizing particular information for the necessary problems and encoding it into a set of production rules. Because the literature is very descriptive and exhaustive it provided an excellent source for information to formulate rules. These rules contained many of the items that affect removal of cows from the herd.

Abduction is the reverse of the cause and effect relationship often seen in scientific analysis. An example of a cause and effect implication is a disease causes an illness and then its effects are observed as symptoms (e.g., mastitis). When in a diagnostic situation this cause and effect relationship must be reversed. The use of a cause and effect relationship in the reverse direction is called abduction.
When using this abduction process it is often beneficial to use elimination rules. These rules can narrow the causative management practices or diseases.

The rules were grouped into blocks according to the particular functions they provided. For example, there were initial rules that helped identify the dairy herd name, the cows identification, medians that were necessary for future computations, etc. The expert system was then further broken down into three large blocks. Each block evaluated a different general area. The first area was reproductive performance of the animal, the second health status, the third, production performance of the animal. Within each block of rules the initial rule helped to identify whether or not the user needed to continue through that block of rules. For example, if the animal under consideration had no health problems there was no reason to ask all of the questions concerning health problems. If, however, that animal did have a health problem then more specific questions needed to be asked about that animal.

Several points important in developing the expert system include the following: first, identify important management problems that impact cow culling; second, discover the data and the heuristics used to diagnose these problems; third, establish an analytical step by step procedure to determine the severity of the problem; and fourth, ascertain what management recommendations should be followed to correct the problem.
The knowledge base was programmed to include all of the variables identified. The system rules were added to allow each of the modules to be tested independently from the entire knowledge base. The reproductive, health and production modules were completed. Additional rules were added to integrate the system in preparation for its verification and validation.

Testing and Evaluation

To test the knowledge base, several processes were used, the first of which was verification. Verification involved insuring that the computer code was written without errors. The expert system shell VP Expert was designed to evaluate each rule to ensure that each of the essential parts was contained within that rule. The verification process was greatly enhanced through the use of this feature in VP Expert. The shell provides an option to aid in evaluation of the rules as they are sequenced. This can help debug logical errors in the knowledge base. When using this option the monitor display is split into three windows. The top window shows a smaller view of what would normally be seen by the user, the two bottom windows show the rules as they are searched and a collection of the rules that help in obtaining the solution.

To evaluate rule redundancy and other logical errors, the written code was studied and each rule evaluated for its
contribution to the solution. These rules were then compared with the others in that particular block.

The second phase was the validation phase. Validation is more difficult. It involves the more deceptively difficult task of insuring that the content and the meaning of the rules meet the logical sequence defined by the literature or the experts involved.

One of the first validation processes was asking whether or not the prototype was defined narrowly enough to solve the original problem. It was recognized that knowledge based projects have a much greater likelihood of succeeding and, in this sense, being valid when they are narrowly focused on a specific problem. Validation is a subjective evaluation based on several areas including: adaptability, adequacy, appeal, realism, usefulness and wholeness. The second point that must be evaluated in a validation process is whether or not those parameters that the expert system evaluates are useful. Do they contain the necessary information to aid in solving the question asked of the expert system.

Twenty herds currently enrolled in the DHI record keeping program in eastern Idaho were selected for inclusion in the study. These herds were identified by the Idaho Extension service as dairies whose managers were progressive and would make efforts to improve their management practices. Only herds were selected that had been in operation for at least one year and based on current plans
would be in operation using DHI for at least one more year. These herds averaged 83 cows per herd with an average annual milk production of 8383 kg/cow. Annual fat production per cow was 298.3 kg. All but two of the herds consisted of Holstein cows with the remaining two being Jersey herds. Sixteen of the herds were managed by the owner, three had a partnership arrangement with both partners contributing to the culling decision, and the final herd was owned by a corporation, a manager and an assistant manager sharing responsibility for the culling decisions. There was an average of 29.3% of the cows per year leaving the herd on the twenty farms. Cows in these dairies were housed using either loose or freestall barns. One dairy used a flat barn for milking while the others used parlors. The forage used in the rations was alfalfa hay and in a few dairies this was supplemented with corn silage.

These dairies were randomly assigned to either the control group or the test herds. The randomization was done by means of a random number table. Preliminary information was obtained from the herd summary sheets and a survey completed about the dairies (25,42).

Each month DHI Provo compiled the necessary information for analysis with the expert system. The information was obtained at the normal test period. The selected information was compiled and sent through the mail to provide the best turn around time for the information. The cows in the 10 experimental herds were then evaluated with
the expert system. The output was mailed to the dairymen and a copy kept for further comparisons.

The statistical method used most frequently by researchers during the validation process has been chi-square or goodness of fit model and was the test used in this part of the study. Comparisons were made between computer suggestions and the dairymen's actions made over the next three month period. Three months were selected to allow for any delay in the decision of the dairymen. Comparisons between the cows suggested culled by the computer and the actual culls made by the dairymen were made with the 10 herds that the MAXCULL program was used to evaluate. The dairymen were encouraged to use the listing from the expert system in making their culling decisions. This was completely voluntary. At the completion of one year using the expert system as an aid, actual records were compared against the suggestion of the program to determine significant differences in agreement. Chi-square tests were performed to identify differences (49).

Herd data comparing the ten control herds with the ten experimental herds were compared for the variables to see if any differences existed. The managers of the control herds were given no additional information, but were encouraged to make wise decisions when considering which cows to cull. Considerable variation was encountered in the data maintained by the dairyman and made available for the study. This was most obvious for the health data. The herd data
were analyzed by least squares techniques using the beginning value for each variable as the covariate. The General Linear Model procedures of SAS were used for the statistical evaluation (49).
RESULTS AND DISCUSSION

Evolvement of the Expert System

VP Expert and Super Expert run on an IBM PC/XT/AT or compatible computer with at least 256K of memory and one double-sided disk drive. As the size of the knowledge base increased the memory requirements of the computer also increase. The expert system developed, named MAXCULL, requires 640K to handle the shell and the knowledge base in the memory. Better performance of the system is obtained with computers using a hard disk or a second floppy drive.

The system is programmed to search for an acceptable solution. The output variables must be identified along with the input variables.

The outputs (type of goals) that the expert system was programmed to assess are shown in Table 3. The input variables used in the MAXCULL program are listed as they are found in the knowledge base along with the block of rules and possible choices available from the menus when appropriate (Table 4). Explanation about the meaning of the abbreviations used to designate less known variables are included in Tables 3 and 4.

Examples of a menu option might consist of possible answers to the question "Which disease did this cow have?," Metabolic, Ketosis, Displaced abomasum, Feet & leg problems and None of the above.
### TABLE 3. Objectives or goals in THEN statements from MAXCULL

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Status of cow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good_Cow</td>
<td>Contributing to fixed &amp; variable Cost</td>
</tr>
<tr>
<td>OK_Cow</td>
<td>No reproductive or health problems</td>
</tr>
<tr>
<td>Reproductive_Cull</td>
<td>Cull cow due to reproductive problems</td>
</tr>
<tr>
<td>Latent_Rep_Cull</td>
<td>Reproductive problems leading to culling</td>
</tr>
<tr>
<td>Potential_Rep_Cull</td>
<td>Reproductive problems, can be corrected</td>
</tr>
<tr>
<td>Influence_Rep</td>
<td>Some factors affecting reproduction</td>
</tr>
<tr>
<td>Heat_Det_Prob</td>
<td>Management factors affect heat detection</td>
</tr>
<tr>
<td>Concept_Prob</td>
<td>Management factors affect conception</td>
</tr>
<tr>
<td>Health_Cull</td>
<td>Cull cow due to health problems</td>
</tr>
<tr>
<td>Latent_Cull</td>
<td>Health problems leading to culling</td>
</tr>
<tr>
<td>Potential_Cull_Cull</td>
<td>Health problems, can be corrected</td>
</tr>
<tr>
<td>Cull</td>
<td>Below break-even production</td>
</tr>
<tr>
<td>Delay_Cull</td>
<td>Low production and other problems could cause culling if correction aren't made</td>
</tr>
<tr>
<td>Possible_Cull</td>
<td>Factors are present and production is low enough to cause future culling</td>
</tr>
<tr>
<td>Potential_Cull</td>
<td>Factors present that can effect cow performance</td>
</tr>
<tr>
<td>Poss._Genetic_Cull</td>
<td>Cull on low production, missing genetic information</td>
</tr>
<tr>
<td>Genetic_Cull</td>
<td>Cull due to low production, cow has a low cow index</td>
</tr>
</tbody>
</table>

1. These objectives were used in the programming of the expert system. Spaces are not allowed so underline characters were used to separate words. Further breakdowns would be beneficial with future versions.

Once the IF statements for a rule are found to be true, the actions listed in the THEN statement are discharged.

Two shells were programmed with the basic rule structure, Super Expert (see Appendix 4) and VP Expert (see Appendix 1). Both shells use an inference engine with a control sequence known as "backward chaining." Using this method each conclusion is established as a goal. All rules
TABLE 4. Input variables used in MAXCULL.

<table>
<thead>
<tr>
<th>Variable1</th>
<th>Block2</th>
<th>Choices3</th>
</tr>
</thead>
<tbody>
<tr>
<td>HerdName</td>
<td>Program</td>
<td>No Limit</td>
</tr>
<tr>
<td>Herd_Daily$</td>
<td>Program</td>
<td>No Limit</td>
</tr>
<tr>
<td>Repro_Problem</td>
<td>Reproduction</td>
<td>LT_120 DIM</td>
</tr>
<tr>
<td>DIM</td>
<td>Reproduction</td>
<td>GE_120 DIM</td>
</tr>
<tr>
<td>Abort</td>
<td>Reproduction</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Serv_Conc</td>
<td>Reproduction</td>
<td>LE_3 Services</td>
</tr>
<tr>
<td>Infect_Uteri</td>
<td>Reproduction</td>
<td>GT_3 Services</td>
</tr>
<tr>
<td>Repro_Factors</td>
<td>Reproduction</td>
<td>Retained Placenta</td>
</tr>
<tr>
<td>Health_Prob</td>
<td>Health</td>
<td>Dystocia</td>
</tr>
<tr>
<td>D_A</td>
<td>Health</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Mastitis</td>
<td>Health</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Injury_U</td>
<td>Health</td>
<td>Yes, No</td>
</tr>
<tr>
<td>Udder_Prob</td>
<td>Health</td>
<td>Broken Udder Support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Udder Edema</td>
</tr>
<tr>
<td>Influence_Hlth</td>
<td>Health</td>
<td>No Udder Problems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ketosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Milk_Fever</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Downer_Cow Syndrome</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Infective Disease</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Respiratory Problems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Health Problems</td>
</tr>
<tr>
<td>Type</td>
<td>Health</td>
<td>Feet &amp; Leg Problems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Injuries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poor_Type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Health Problems</td>
</tr>
<tr>
<td>FCM</td>
<td>Production</td>
<td>GT_Zero, LE_Zero</td>
</tr>
<tr>
<td>Genetic</td>
<td>Production</td>
<td>Not_Available</td>
</tr>
</tbody>
</table>

The system requires that all variables be identified.

1. The variables selected must be abbreviated for performance reasons. Most are self explanatory. Herd_Daily$ represents the median value of product sold daily, DIM represents days in milk, D_A means displaced abomasum, Injury_U represents injuries to the udder, FCM represents fat corrected milk.

2. This identifies which block of rules uses the variable.

3. Explains what answers could be chosen for the questions related to each variable. LT_120 means less than 120 DIM, GE_120 means 120 DIM or greater, LE_3 means 3 services or less, GT_3 means more the 3 services, GT_0 means cow index greater than 0 and LE_0 means 0 or less.
that infer this conclusion are looked at in the order from first rule to last. If a rule cannot be evaluated because of unknown information it is suspended. The program can only proceed after information is obtained from the user or from other rules contained in the knowledge base.

The system will request information needed by asking the user to provide information that will help in reaching a conclusion for the rules. An example of this control method is shown in Figure 1. This is how a cow with greater than 120 days open, no abortion, services/conception less than three and having a uterus infection would track through the knowledge base. Bold type indicates acceptance of information in the rule.

In Figure 1 a set of rules is displayed. In this set of rules, each rule requires an evaluation of a preceding rule. The first line of code requests the inference engine to find a solution. The inference engine then proceeds through the rules listed until in rule 16 all of the If clauses are found to be true allowing the Then clause to be executed. Each rule must be evaluated to provide some of the data to help reach the conclusion. This particular figure demonstrates the effect of a backward chaining strategy described above.

The VP Expert shell uses a rule base with up to five parts: if premises, then statements, optional else statements, a reasoning section, and programming codes. The if and then statements were demonstrated in Figure 1. Else
FIND Projection

IF Repro_Problem = No
THEN Projection = OK_Cow

RULE R1
IF DIM = LT 120 AND Abort = Yes
THEN Projection = Latent_Rep_Cull

RULE R2
IF DIM = GE 120 AND Abort = Yes
THEN Projection = Reproductive_Cull

RULE R3
IF DIM = GE 120 AND Abort = No AND Serv_Conc = GT 3 AND Infect_Uteri = Yes
THEN Projection = Reproductive_Cull

RULE R13
IF DIM = GE 120 AND Abort = No AND Serv_Conc = LE 3 AND Infect_Uteri = No AND Repro_Factors = Other OR Repro_Factors = Retained_P OR Repro_Factors = None OR Repro_Factors = Dystocia
THEN Projection = Potential_Rep_Cull

RULE R16
IF DIM = GE 120 AND Abort = No AND Serv_Conc = LE 3 AND Infect_Uteri = Yes
THEN Projection = Latent_Rep_Cull

FIGURE 1. An example of rule sequence.
statements were not used extensively in the MAXCULL program to avoid logic errors. The reasoning section was useful in giving explanations. The programming codes allowed the system to perform activities that increase the friendliness of the program and to speed up the process.

The prototype program was written to represent some of the rules in a way that would be useful. It was realized that in the initial stages these rules would be revised many times. The primary purpose for writing the initial prototype was to identify methods as well as inputs that needed to be added and revised through the process.

Daily value of product, provided by DHI on the custom report designed for this study, was used to help approximate the point in the herd where milk production was profitable. More exact measures of identifying costs that would help in establishing the break-even point were explored. Many dairymen felt that any information submitted on costs would only be estimates and no more accurate than this approximation. The median daily value of product was recorded in the software, then the program approximated breakeven by computing 75 percent of the median.

With the additional understanding gained from the evaluation of the rules and the selected problems used in evaluating the prototype, the system was restructured. This marked the start of development of the version which was intended to be field tested. This version was identified as the Mark II prototype.
While working on the Mark II prototype redundant data were eliminated. Efforts were exerted to insure that rules were complete and provided missing rule information. The process of building an expert system is inherently empirical.

Specifically, the MAXCULL program did the following: (1) asked for identification of the animal; (2) evaluated the reproductive status of the cow based on days open, pregnancy and other reproductive items; (3) evaluated the health status of the animal (e.g., mastitis, feet and leg problems, dystocia) (see Figure 1); (4) evaluated the animal based on its ranking for daily dollar value of product sold; (5) diagnosed which of these problems were contributing to the economic situation of the animal; (6) issued specific recommendations for avoiding early removal of this animal from the herd or identified those animals which should be removed immediately.

Field Test of MAXCULL

The ten MAXCULL herds used the program for a twelve month period (August 1989 through July 1990). The control herds were allowed to cull cows based on their usual method with no outside direction. Following the twelve month period, field data of the thirteen variables were collected from the herd summaries of both the MAXCULL and the control herds. The results of the evaluation of these data between the control and MAXCULL herds are summarized in Table 5.
The value for each parameter was compared using the beginning value recorded from the August 1989 test date for that parameter as the covariate. Least square means (LSMEANS) for all variables, except %DIM and Avg days open, were not different between the control and MAXCULL groups. Cows managed with the additional information provided by the Expert System program, MAXCULL, had similar production and reproductive measures as the control group.

Only two of the 204 cows evaluated for health reasons were suggested as possible culls. Seventy-four of the 598 total cows evaluated from the ten herds were suggested as culls primarily for low production. Twenty-four cows also had a secondary cause for culling related to reproductive problems. One hundred seventy seven cows were suggested as reproductive culls and all but nineteen had secondary reasons for removal for low production.

Means of the cows removed from the ten experimental herds were compared by status for removal. Cows considered removed would fall into categories called status groups of sold for beef, sold for dairy, dry and died. Table 6 shows that milk production and average days in milk were significantly greater for those animals that died (9) when compared to those that were culled for beef (8).

Those animals sold for dairy purposes had no greater daily milk production, but were culled earlier in their lactations. These cows also had higher fat percent and lower somatic scores, only Avg DIM was significantly
TABLE 5. Means, standard deviations and probabilities for herds using MAXCULL compared to control herds. 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>MAXCULL LSMEANS</th>
<th>Std Err LSMEANS</th>
<th>CONTROL LSMEANS</th>
<th>Std Err LSMEANS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME Milk (kg)</td>
<td>28689</td>
<td>168</td>
<td>8920</td>
<td>168</td>
</tr>
<tr>
<td>ME Fat (kg)</td>
<td>282.7</td>
<td>35.5</td>
<td>300.8</td>
<td>35.5</td>
</tr>
<tr>
<td>% Leaving (%)</td>
<td>30.23</td>
<td>2.89</td>
<td>28.47</td>
<td>2.89</td>
</tr>
<tr>
<td># of Cows (#)</td>
<td>110</td>
<td>2.88</td>
<td>113</td>
<td>2.88</td>
</tr>
<tr>
<td>Daily Milk (kg)</td>
<td>22.04</td>
<td>0.89</td>
<td>24.08</td>
<td>0.89</td>
</tr>
<tr>
<td>Daily Fat (kg)</td>
<td>0.85</td>
<td>0.05</td>
<td>0.93</td>
<td>0.05</td>
</tr>
<tr>
<td>% DIM (%)</td>
<td>81</td>
<td>1.62</td>
<td>86</td>
<td>1.53</td>
</tr>
<tr>
<td>Avg DIM (#)</td>
<td>180</td>
<td>8.45</td>
<td>183</td>
<td>8.45</td>
</tr>
<tr>
<td>SCC LOG</td>
<td>2.84</td>
<td>0.45</td>
<td>2.90</td>
<td>0.42</td>
</tr>
<tr>
<td>Ser/Conc(#)</td>
<td>1.79</td>
<td>0.11</td>
<td>1.62</td>
<td>0.11</td>
</tr>
<tr>
<td>Avg Days Open</td>
<td>133</td>
<td>4.55</td>
<td>114</td>
<td>4.54</td>
</tr>
<tr>
<td>Calving Int</td>
<td>13.1</td>
<td>0.17</td>
<td>13.4</td>
<td>0.17</td>
</tr>
<tr>
<td>Avg Days Dry</td>
<td>64.7</td>
<td>3.27</td>
<td>63.7</td>
<td>3.27</td>
</tr>
</tbody>
</table>

1. The variables listed were from the July 1990 herd summary with a covariate of the variable from the August 1989 herd summary. The MAXCULL group included the ten herds using the MAXCULL expert system to evaluate cows to be culled. The control herds used the traditional methods they had used previously.

2. ME - represents Mature Equivalent production of either milk or fat. These values are based on standardization procedures used by the dairymen when comparing annual production of cows.

3. % leaving - is the percent of animals leaving the herd for any reason.

4. % DIM - is the percent of the total herd that is milking.

5. Avg DIM - is the average days in milk for that group of cows.

6. SCC LOG - is the LOG base two of the somatic cell count as reported by DHI labs.

Ser/Conc(#) - is the number of services to achieve a conception.
### TABLE 6. Comparison of cows identified by MAXCULL as potential culls.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Measure</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk (kg)</td>
<td>LSMEAN</td>
<td>8.66</td>
<td>17.54</td>
<td>18.00</td>
<td>27.63</td>
</tr>
<tr>
<td></td>
<td>Std Err Mean</td>
<td>4.73</td>
<td>1.58</td>
<td>0.40</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>Prob /8</td>
<td>0.05</td>
<td>0.78</td>
<td>.</td>
<td>0.01</td>
</tr>
<tr>
<td>% Fat</td>
<td>LSMEAN</td>
<td>4.40</td>
<td>4.40</td>
<td>3.99</td>
<td>5.10</td>
</tr>
<tr>
<td></td>
<td>Std Err Mean</td>
<td>2.18</td>
<td>0.73</td>
<td>0.18</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Prob /8</td>
<td>0.85</td>
<td>0.58</td>
<td>.</td>
<td>0.04</td>
</tr>
<tr>
<td>Avg DIM</td>
<td>LSMEAN</td>
<td>346.50</td>
<td>160.60</td>
<td>229.48</td>
<td>144.03</td>
</tr>
<tr>
<td></td>
<td>Std Err Mean</td>
<td>75.39</td>
<td>25.13</td>
<td>6.45</td>
<td>17.77</td>
</tr>
<tr>
<td></td>
<td>Prob /8</td>
<td>0.12</td>
<td>0.00</td>
<td>.</td>
<td>0.01</td>
</tr>
<tr>
<td>SCC LOG</td>
<td>LSMEAN</td>
<td>582</td>
<td>404</td>
<td>612</td>
<td>247</td>
</tr>
<tr>
<td></td>
<td>Std Err Mean</td>
<td>782</td>
<td>268</td>
<td>71</td>
<td>202</td>
</tr>
<tr>
<td></td>
<td>Prob /8</td>
<td>0.97</td>
<td>0.45</td>
<td>.</td>
<td>0.08</td>
</tr>
</tbody>
</table>

1. Means with standard deviations and probabilities for variables in different status groups as identified by the dairymen managing the MAXCULL herds. Milk figures represent daily production. Fat levels are recorded in percents. Average days in milk (DIM) refers to the number of days that the animal had been milking when the status change identified occurred. Somatic cell count (SCC) log score is used to monitor mastitis level between groups. Probabilities are comparing the status group identified with those animals in status group 8 (Sold for Beef) as these cows represent the normal cull group.

2. Status group refer to reason given for leaving herd. 6-Dry, 7-Sold for dairy, 8-Sold for beef and 9-Died.

3. Prob/8 gives the probability as compared to status group 8-Sold for Beef.

different between those cows identified as culled for beef and dairy.

Those animals actually removed from the experimental herds that would be considered culled for beef purposes had the lowest level of fat percent and the highest somatic cell levels. These cows were nearly 230 days into their lactation on average when removed.
To test whether the knowledge base is functional refers to how it matches expert intuition and stimulates thought. This must be tested by the interaction of the system with the consumer or in this case the dairyman. The chi square analysis showed a significant difference between the frequencies of culling decisions made by the computer and the managers (Table 7).

Comparisons made between those cows which the computer suggested as culls and the managers' actions are listed in Table 8. Daily milk production was significantly lower for the group which the MAXCULL program suggested to cull and the manager culled compared to the other two groups. Many of the cows removed by the dairyman could have left partially due to other reasons that were not recorded and available to the computer.

Percent fat levels were not significantly different between the three groups. Average days in milk were significantly different between those animals that the computer suggested as possible culls and those cows kept for various reasons by the dairyman. Those cows suggested to be culled by the computer and retained by the dairyman averaged 261 days in milk. Those removed by the dairyman and not flagged as possible culls by the computer were only 176 days in milk.

Further evaluation of the animals with differences in the suggestions by MAXCULL and the action taken by the manager was made on the basis of their removal status (dry,
TABLE 7. Chi-Square table for those cows evaluated with the MAXCULL program compared to the decisions made by the dairy managers.

<table>
<thead>
<tr>
<th>MAXCULL</th>
<th></th>
<th>Manager</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Y</td>
<td>Total</td>
</tr>
<tr>
<td>---------------</td>
<td>---------</td>
<td>---------------</td>
<td>---------</td>
</tr>
<tr>
<td>Overall %</td>
<td>49.67</td>
<td>8.03</td>
<td>57.69</td>
</tr>
<tr>
<td>Row %</td>
<td>86.09</td>
<td>13.91</td>
<td></td>
</tr>
<tr>
<td>Column %</td>
<td>62.39</td>
<td>39.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>179.00</td>
<td>74.00</td>
<td>253.00</td>
</tr>
<tr>
<td>Overall %</td>
<td>29.93</td>
<td>12.37</td>
<td>42.31</td>
</tr>
<tr>
<td>Row %</td>
<td>70.75</td>
<td>29.25</td>
<td></td>
</tr>
<tr>
<td>Column %</td>
<td>37.61</td>
<td>60.66</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>476.00</td>
<td>122.00</td>
<td>598.00</td>
</tr>
<tr>
<td>Chi Square</td>
<td>21.14</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

1. The left hand column represents MAXCULL's recommendation while the top represents the decision made by the dairy manager. The top number in each set is the frequency of the interaction, the overall percent is what percent of the whole is represented by this comparison. The row percent is the portion in this row found in this group. The column percent is the portion in this column found in this group.

sold for beef or dairy (Table 9, 10). The comparison for percent fat showed only those cows sold for dairy had significant differences from the groups sold for beef, others were not significantly different.

It is also important in the testing stages for the knowledge engineer to identify under what conditions the expert system would be useful. This often involves testing a knowledge base to determine its generality. Generality is defined as the range of context in which that particular system could perform reliably (4). This was partially addressed by the number of times the system
TABLE 8. Comparison of three variables for groups of cows according to agreement of the manager with the computer recommendations.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Comp</th>
<th>Man</th>
<th>LSMEANS</th>
<th>Std Err</th>
<th>LS</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk(kg)</td>
<td>No</td>
<td>Yes</td>
<td>22.36</td>
<td>0.93</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>19.56</td>
<td>0.50</td>
<td>2</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>17.28</td>
<td>0.77</td>
<td>3</td>
<td>0.014</td>
</tr>
<tr>
<td>% Fat</td>
<td>No</td>
<td>Yes</td>
<td>3.84</td>
<td>0.15</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>4.76</td>
<td>0.60</td>
<td>2</td>
<td>0.139</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>3.92</td>
<td>0.13</td>
<td>3</td>
<td>0.170</td>
</tr>
<tr>
<td>Avg DIM</td>
<td>No</td>
<td>Yes</td>
<td>176</td>
<td>15</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>261</td>
<td>8</td>
<td>2</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>237</td>
<td>12</td>
<td>3</td>
<td>0.110</td>
</tr>
</tbody>
</table>

1. Least square means, standard error of the mean and probability comparisons for daily milk, percent fat and days in milk (DIM). The computer (Comp) column identifies whether the computer recommended the animals in the group to be culled or not. The manager (Man) column describes the status of the animal as reported on the cow barn sheet over the period of the study.

TABLE 9. Least square means (LSMEANS), standard error of the mean (Std Err LSMEANS) and probabilities for fat percent by removal status and MAXCULL recommendation (Comp).

<table>
<thead>
<tr>
<th>Status</th>
<th>Comp</th>
<th>N</th>
<th>LSMEANS</th>
<th>Std Err</th>
<th>Probabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LSMEANS 1</td>
</tr>
<tr>
<td>Sold/dairy</td>
<td>No</td>
<td>10</td>
<td>4.12</td>
<td>0.45</td>
<td>1</td>
</tr>
<tr>
<td>Sold/dairy</td>
<td>Yes</td>
<td>9</td>
<td>4.86</td>
<td>0.34</td>
<td>2 0.19</td>
</tr>
<tr>
<td>Sold/beef</td>
<td>No</td>
<td>38</td>
<td>3.77</td>
<td>0.17</td>
<td>3 0.47 0.00</td>
</tr>
<tr>
<td>Sold/beef</td>
<td>Yes</td>
<td>61</td>
<td>3.75</td>
<td>0.13</td>
<td>4 0.44 0.00 0.93</td>
</tr>
</tbody>
</table>
was exposed to that portion of the database. The health block lacked exposure because of lack of information. The reproductive and productive blocks had a broader variety of information used in analyzing the cows from the experimental herds. These blocks had cows from the MAXCULL herds used in the evaluation each time. This provided a favorable situation for the evaluation.

Thus, the validation process is assessing whether or not the knowledge base can produce correct predictions, given that the system has access to the information that it needs. The MAXCULL system was not validated by the comparison made in this study. The lack of information from many of the cows could partially explain the difference between the managers decision and the computer's recommendations when evaluating reasons for removing the cows.

Nearly half of the herds were missing information that could have been helpful in determining breeding values. Many dairymen cannot see the benefits of complete records and management information.
Table 11 reports the response of dairymen with respect to their feelings about using computers. The dairymen's answers were well thought out and very candid. These dairymen were aware of the challenges faced in software development and excited about the potential for advances in computer information.

Table 11. Responses to survey of reaction to computer-aided management.

<table>
<thead>
<tr>
<th>Question</th>
<th>Percent affirmative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was the output you received from MAXCULL received in a timely manner?</td>
<td>60%</td>
</tr>
<tr>
<td>Are computers useful as management tools?</td>
<td>100%</td>
</tr>
<tr>
<td>Would you use advice given by a computer?</td>
<td>100%</td>
</tr>
<tr>
<td>Should researchers continue to develop computer systems to aid in management of dairies?</td>
<td>100%</td>
</tr>
<tr>
<td>What areas of dairy management would you benefit from future computer software development?</td>
<td></td>
</tr>
<tr>
<td>1. Finance</td>
<td>(3)</td>
</tr>
<tr>
<td>2. Mastitis</td>
<td>(2)</td>
</tr>
<tr>
<td>3. Bull selection, breeding</td>
<td>(2)</td>
</tr>
<tr>
<td>4. Calf Raising</td>
<td>(2)</td>
</tr>
<tr>
<td>5. Records</td>
<td>(2)</td>
</tr>
<tr>
<td>6. Reproduction</td>
<td>(1)</td>
</tr>
<tr>
<td>7. Nutrition</td>
<td>(1)</td>
</tr>
</tbody>
</table>
CONCLUSIONS

The following conclusions were drawn by the researcher, based on his interpretation of the data and information presented in this study.

1. The expert system MAXCULL and the dairyman differed in their culling process.

Although management software programs have been placed in the market place, acceptance and application has not been widespread among agricultural producers. It is estimated that less than ten percent of all farms in the United States currently use personal computers for management decisions (62). Reasons for this low level of use can be explained by several factors that are related to existing technology. First, current hardware and software require knowledge of computers and application of software with communication requirements that are unfamiliar to most managers. Second, the software lacks the ability to communicate in a "natural language" manner. Third, standard programming does not provide the needed interactive reasoning capabilities often needed by farmers. Expert systems can provide a framework that can overcome these three limitations. No previous computer knowledge is required by the user and there is a natural language interface for the end user. The expert system is also interactive, generating advice and helping develop solutions in a particular problem area through the interactive management system.
Each rule is a fragment of reasoning knowledge consisting of various parts. The rules govern the parameters of each production management function and dictate the final recommendation to the user. Human experts do not solve problems through heuristics or rules of thumb alone. Many times the human expert must apply analytical and other reasoning skills to the problem solving process. Expert system shells lack this dimension.

With expert systems, knowledge and experience of researchers can be encapsulated so dairy managers can benefit from those efforts. The MAXCULL system was designed to use information that was typically used by managers.

Test results indicate that differences occurred between the MAXCULL and the managers in identifying cows to cull, given the information available from DHI. Animals may be culled by the manager with higher levels of production because the managers studied had specific information not available to the computer program.

2. Access to information is critical. Correct decisions cannot be made by the dairyman or some program without complete and accurate information.

MAXCULL would be more beneficial in situations where the dairyman has immediate access to a computer and the expert system. It would also be more useful if it could actively interact with the current database that the dairyman uses to hold the information for his cows. This would expedite the analysis and allow the dairyman to
interact with the program to evaluate alternatives in a what-if scenario. As computers become adopted more widely and software is developed, expert systems can play an increasing role in providing added information to managers.

Expert systems can provide producers with advice for management decision-making on an ongoing basis. They are not involved in courses, meetings, research or vacations. Production related expert systems provide consistent, methodical and reliable assistance. The challenge comes in identifying which variables are key to the decision and what the outcomes should be.

Expert systems, such as MAXCULL, could be helpful in creation of the list of animals to be culled. For this to work, dairy managers would need to record information on health and type of the cow. These data with current information on reproduction and production information could then be used to identify cows to cull.

3. Simulation testing could be used to further refine MAXCULL.

The adequacy of the system, meaning the fraction of pertinent observations that can be simulated, is difficult to identify but still needs to be addressed. Established lists of parameters such as variables, conditions, and relations that influence the inference outcomes and determine what to include in the rule set have been listed. Involvement with experts to further refine the means by
which the variables influence removal will need to be extended.

4. Expert systems can be used to provide advice for dairymen.

5. Computer generated advice is accepted by the dairymen. The exit interview with the dairymen provided positive feedback on the usefulness of a system such as MAXCULL. They felt that expert advice from computers would be helpful and they would welcome any help that would be provided by such systems.
RECOMMENDATIONS FOR FURTHER STUDY

The researcher recognizes that this has been a study into an area about which little is known, in which little research has been done, and in which many new findings will help in assembling facts important to the progress of computer use with dairies in the future. A number of areas need further research. Some that seem apparent to the researcher include:

1. Breadth and depth of the knowledge base must be evaluated to determine if the number of rules involved are of a general nature and are too broadly conceived for the problem at hand. The depth of a problem looks at the number and kinds of variables chosen to describe each of the different parts of the model. It involves the range of conditions that the system will address and which parameters are necessary to diagnose, classify, and or advise for each condition. The depth helps in turn to determine the necessary input data and the user interface.

2. Realism is particularly important when developing a full scale knowledge base and also involves the logical order in which queries are made.

3. When developing expert systems for use in management situations it would be easier to use simulation and modeling to test the system for initial validity problems. These models could be monitored to insure that all possible scenarios occur forcing the expert system to evaluate many
varied situations. Only after it has met all imaginable situations created through the simulation should it be sent into the field for further evaluation. MAXCULL needs this type of simulation testing to modify it to meet the prescribed requirements before it can be further field tested. With the rapid advances in computers, sensors and input devices, expert systems will be needed to capture large amounts of data and distill out the critical information for the manager.

4. To adequately test such a system better records need to be available to the researcher. Stand alone computer systems could provide the flexibility and type of information needed. Volume of records would be the greatest concern.
LITERATURE CITED


Appendix A. MAXCULL Program Using VP-Expert.

RUNTIME;
EXECUTE;
ENDOFF;
ACTIONS

WOPEN 1,2,4,8,69,5
ACTIVE 1
DISPLAY "This expert system advises you on which cows to remove from your herd based on the health, reproductive and production information supplied.

Press any key to begin the consultation.~"

CLS
FIND Herdname
CLS
FIND Herd_Daily$
Low_Val = (Herd_Daily$ * .75)
FORMAT Herd_Daily$, 5.2
FORMAT Low_Val, 5.2
PDISPLAY
"============================================================================
This report is for {Herdname}.
The average value for product in the herd is {Herd_Daily$}.
The estimated breakeven used is {Low_Val}.
============================================================================

WOPEN 2,11,3,10,71,4
WOPEN 3,12,4,8,69,1
LOCATE 2,2
ACTIVE 1
CLS
WHILEKNOWN Cow_Number
PRINTON
FIND Cow_Number
ACTIVE 3
PDISPLAY "

This analysis is for cow number {Cow_Number}.

FIND Projection
FIND Suggestion
FIND Recommendation
RESET Repro_Problem
RESET Reproduction
RESET Abort
RESET Projection
RESET DIM
RESET Infect_Uteri
RESET Repro_Factors
RESET Serv_Conc
RESET Health_Prob
RESET Serious
RESET D_A
RESET Health
RESET Suggestion
RESET Injury_U
RESET Udder_Prob
RESET Influence_Health
RESET Type
RESET Mastitis
RESET Genetic
RESET FCM
RESET Recommendation
RESET Cow_Number
ACTIVE 1
CLS
FIND Cow_Number
PRINTOFF

END;

ASK Herdname: "What is this herds name?";

ASK Cow_Number: "What is this cows identification name or number?";
(or Enter ? to exit.)"

ASK Herd_Daily$: "What is the herd's average daily dollar value for product?";

RULE REPRO
IF Repro_Problem=No
THEN Projection=OK Cow
DISPLAY "The reproductive condition of this cow is satisfactory.";

ASK Repro_Problem: "Has this cow had any reproductive problems?";
CHOICES Repro_Problem: Yes, No;

RULE R1
IF DIM=LT 120 AND Abort=Yes
THEN Projection=Latent_Rep_Cull
DISPLAY "This cow's abortion early in lactation places her in a critical reproductive management situation.";

RULE R2
IF DIM=GE 120 AND Abort=Yes
THEN Projection=Reproductive_Cull
DISPLAY "This cow's abortion later in lactation makes her a likely cull."

RULE R3
IF
  DIM=GE 120 AND
  Abort=No AND
  Serv_Conc=GT 3 AND
  Infect_Uteri=Yes
THEN
  Projection=Reproductive_Cull
DISPLAY "The poor conception and uterine infection rank this cow to be in a critical reproductive management situation."

RULE R4
IF
  DIM=LT 120 AND
  Abort=No AND
  Serv_Conc=LE 3 AND
  Infect_Uteri=Yes AND
  Repro_Factors=Dystocia OR
  Repro_Factors=Retained_P OR
  Repro_Factors=Cystic OR
  Repro_Factors=Other
THEN
  Projection=Potential_Repro_Cull
DISPLAY "The uterine infection and other reproductive factors rank this cow as a potential Reproductive cull if changes don't occur."

RULE R5
IF
  DIM=LT 120 AND
  Abort=No AND
  Serv_Conc=GT 3 AND
  Infect_Uteri=No AND
  Repro_Factors=Other
THEN
  Projection=Potential_Repro_Cull
DISPLAY "The poor conception and other reproductive problems rank this cow to be in a poor reproductive management situation."

RULE R6
IF
  DIM=LT 120 AND
  Abort=No AND
  Serv_Conc=LE 3 AND
  Infect_Uteri=No AND
  Repro_Factors=None
THEN
  Projection=OK_Cow
DISPLAY "The reproductive condition of this cow is satisfactory."

RULE R7
IF
  DIM=LT 120 AND
  Abort=No AND
  Serv_Conc=GT 3 AND
  Infect_Uteri=Yes
THEN
  Projection=Latent_Repro_Cull
DISPLAY "The poor conception and uterine infection rank this cow to be in a poor reproductive management situation.";

RULE R8
IF
DIM=LT 120 AND
Abort=No AND
Serv_Conc=LE 3 AND
Infect_Uteri=Yes AND
Repro_Factors=None
THEN
Projection=Influence_Rep
DISPLAY "The uterine infection indicates a potential reproductive problem.";

RULE R9
IF
DIM=LT 120 AND
Abort=No AND
Serv_Conc=LE 3 AND
Infect_Uteri=No AND
Repro_Factors=Cystic OR
Repro_Factors=Retained_P OR
Repro_Factors=Other OR
Repro_Factors=Dystocia
THEN
Projection=Influence_Rep
DISPLAY "This cow shows some reproductive problems that should be watched.";

RULE R10
IF
DIM=LT 120 AND
Abort=No AND
Serv_Conc=GT 3 AND
Infect_Uteri=No AND
Repro_Factors=None
THEN
Projection=Heat_Det_Prob
DISPLAY "The excessive services indicates a possible heat detection problem or other unidentified problems that effect conception for this cow.";

RULE R11
IF
DIM=LT 120 AND
Abort=No AND
Serv_Conc=GT 3 AND
Infect_Uteri=No AND
Repro_Factors=Cystic
THEN
Projection=Potential_Rep_Cull
DISPLAY "The uterine infection and cystic ovaries of this cow at this stage of lactation could cause her removal if changes aren't coming.";

RULE R12
IF
DIM=LT 120 AND
Abort=No AND
Serv_Conc=GT 3 AND
Infect_Uteri=No AND
Repro_Factors=Dystocia OR Repro_Factors=Retained_P
THEN Projection=Concept_Prob
DISPLAY "The excessive services indicates a possible heat detection problem or other unidentified problems that effect conception, such as calving difficulties, for this cow.";

RULE R13
IF DIM=GE_120 AND Abort=No AND Serv_Conc=LE_3 AND Infect_Uteri=No AND Repro_Factors=Other OR Repro_Factors=Retained_P OR Repro_Factors=None OR Repro_Factors=Dystocia
THEN Projection=Potential_Rep_Cull
DISPLAY "The excessive days in milk or other unidentified problems indicate a potential reproductive problem.";

RULE R14
IF DIM=GE_120 AND Abort=No AND Serv_Conc=LE_3 AND Infect_Uteri=No AND Repro_Factors=Cystic
THEN Projection=Latent_Rep_Cull
DISPLAY "The excessive days in milk and cystic ovaries of this cow at this stage of lactation could cause her removal if changes aren't coming.";

RULE R15
IF DIM=GE_120 AND Abort=No AND Serv_Conc=GT_3 AND Infect_Uteri=No
THEN Projection=Latent_Rep_Cull
DISPLAY "The poor conception rate of this cow at this stage of lactation could cause her removal if changes aren't coming.";

RULE R16
IF DIM=GE_120 AND Abort=No AND Serv_Conc=LE_3 AND Infect_Uteri=Yes
THEN Projection=Latent_Rep_Cull
DISPLAY "This cow's uterine infection this late in her lactation makes her a likely reproductive cull.";
ASK Abort: "Has this cow aborted during this lactation?";
CHOICES Abort: Yes, No;

ASK DIM: "Cows current Days In Milk?";
CHOICES DIM: GE_120, LT_120;

ASK Serv_Conc: "How many times has this cow been bred during this lactation?";
CHOICES Serv_Conc: GT_3, LE_3;

ASK Infect_Uteri: "Has this cow had a Uterine_Infection during this lactation?";
CHOICES Infect_Uteri: Yes, No;

ASK Repro_Factors: "Has this cow had any of these reproductive problems?";
CHOICES Repro_Factors: None, Cystic, Other, Retained_P, Dystocia;

RULE Health
IF Health_Prob=No
THEN Suggestion=OK_Cow
DISPLAY "The health condition of this cow is satisfactory."

ASK Health_Prob: "Has this cow had any health problems this lactation?";
CHOICES Health_Prob: Yes, No;

RULE H0
IF D_A = Yes
THEN Suggestion = Health_Cull
DISPLAY "This cow's displaced abomasum makes her a likely health cull."

ASK D_A: "Has this cow had a displaced abomasum this lactation?";
CHOICES D_A: Yes, No;

RULE H1
IF Mastitis=Yes AND Injury_U=Yes AND Udder_Prob=Edema OR Udder_Prob=Slow_Milker OR Udder_Prob=Broken_Udder_Support OR Udder_Prob=Two_or_more
THEN Suggestion=Health_Cull
DISPLAY "This cow's mastitis and other udder related problems rank this cow as a health related cull."

RULE H2
IF Mastitis=Yes AND Injury_U=Yes AND
RULE H3
IF Mastitis=Yes AND Injury_U=Yes AND Udder_Prob=None AND Influence_Health=None AND Type=Injuries OR Type=Poor_Type OR Type=Poor_Behavior OR Type=Other OR Type=Feet_&_Leg OR Type=Two_or_more THEN Suggestion=Health_Cull
DISPLAY "This cow's mastitis and other health problems rank this cow as a health related cull.";

RULE H4
IF Mastitis=Yes AND Injury_U=Yes AND Udder_Prob=None AND Influence_Health=None AND Type=None THEN Suggestion=Latent_Cull
DISPLAY "This cow's mastitis and udder injuries rank this cow to be in a critical health management situation.";

RULE H5
IF Mastitis=Yes AND Injury_U=No AND Udder_Prob=Two_or_more AND Influence_Health=Two_or_more OR Influence_Health=Milk_Fever OR Influence_Health=Downer_Syndrome OR Influence_Health=Infective_Disease OR Influence_Health=Respiratory_Problems OR Influence_Health=Other OR Influence_Health=Ketosis THEN Suggestion=Health_Cull
DISPLAY "This cow's mastitis and other health problems rank this cow as a health cull.";

RULE H6
IF Mastitis=Yes AND
RULE H7
IF       Mastitis=Yes AND
         Injury_U=No AND
         Udder_Prob=Two_or_more AND
         Influence_Health=None AND
         Type=None
THEN   Suggestion=Latent_Cull
DISPLAY "This cow's mastitis, injuries and other udder problems rank this cow to be in a critical health management situation.";

RULE H8
IF       Mastitis AND
         Injury_U=No AND
         Udder_Prob=Edema OR
         Udder_Prob=Slow_Milker OR
         Udder_Prob=Broken_Udder_Support AND
         Influence_Health=Two_or_more
THEN   Suggestion=Health_Cull
DISPLAY "This cow's mastitis and other udder problems rank this cow as a health related cull.";

RULE H9
IF       Mastitis=Yes AND
         Injury_U=No AND
         Udder_Prob=Edema OR
         Udder_Prob=Slow_Milker OR
         Udder_Prob=Broken_Udder_Support AND
         Influence_Health=Milk_Fever OR
         Influence_Health=Downer_Syndrome OR
         Influence_Health=Infective_Disease OR
         Influence_Health=Respiratory_Problems OR
         Influence_Health=Other OR
         Influence_Health=Ketosis
THEN   Suggestion=Latent_Cull
DISPLAY "This cow's mastitis and other health problems rank this cow to be in a critical health management situation.";

RULE H10
IF       Mastitis=Yes AND
Injury_U=No AND
Udder_Prob=Edema OR
Udder_Prob=Slow_Milker OR
Udder_Prob=Broken_Udder_Support AND
Influence_Health=None AND
Type=Two_or_more
THEN Suggestion=Health_Cull
DISPLAY "This cow's mastitis and other health problems rank this cow as a health related cull."

RULE H11
IF Mastitis=Yes AND
   Injury_U=No AND
   Udder_Prob=Edema OR
   Udder_Prob=Slow_Milker OR
   Udder_Prob=Broken_Udder_Support AND
   Influence_Health=None AND
   Type=None
THEN Suggestion=Potential_Cull
DISPLAY "This cow's mastitis and other udder problems rank this cow to be a health management problem."

RULE H12
IF Mastitis=Yes AND
   Injury_U=No AND
   Udder_Prob=None AND
   Influence_Health=Two_or_more OR
   Influence_Health=Milk_Fever OR
   Influence_Health=Downer_Syndrome OR
   Influence_Health=Infective_Disease OR
   Influence_Health=Respiratory_Problems OR
   Influence_Health=Other OR
   Influence_Health=Ketosis
THEN Suggestion=Latent_Cull
DISPLAY "This cow's mastitis and other health problems rank this cow to be in a critical health management situation."

RULE H13
IF Mastitis=Yes AND
   Injury_U=No AND
   Udder_Prob=None AND
   Influence_Health=Two_or_more OR
   Influence_Health=Milk_Fever OR
   Influence_Health=Downer_Syndrome OR
   Influence_Health=Infective_Disease OR
   Influence_Health=Respiratory_Problems OR
   Influence_Health=Other OR
   Influence_Health=Ketosis
THEN Suggestion=Latent_Cull
DISPLAY "This cow's mastitis and other health problems rank this cow to be in a critical health management situation."
RULE H14
IF Mastitis=Yes AND Injury_U=No AND Udder_Prob=None AND Influence_Health=None AND Type=Two_or_more THEN Suggestion=Latent_Cull
DISPLAY "This cow's mastitis and other health problems rank this cow to be in a critical health management situation."

RULE H15
IF Mastitis=Yes AND Injury_U=No AND Udder_Prob=None AND Influence_Health=None AND Ty=None THEN Suggestion=Potential_Cull
DISPLAY "This cow's mastitis and other health problems rank this cow to be in an undesirable health management situation."

RULE H16
IF Mastitis=Yes AND Injury_U=No AND Udder_Prob=None AND Influence_Health=None AND Type=Injuries OR Type=Poor_Type OR Type=Poor_Behavior OR Type=Other OR Type=Feet & Leg THEN Suggestion=Latent_Cull
DISPLAY "This cow's mastitis and other type or management problems rank this cow to be in a critical health management situation."

RULE H17
IF Mastitis=No AND Injury_U=Yes AND Udder_Prob=Edema OR Udder_Prob=Slow_Milker OR Udder_Prob=Broken_Udder_Support AND Influence_Health=Two_or_more THEN Suggestion=Health_Cull
DISPLAY "This cow's udder injuries, udder problems and other health problems rank this cow as a health related cull."

RULE H18
IF Mastitis=No AND Injury_U=Yes AND Udder_Prob=Edema OR
THEN Suggestion=Latent_Cull
DISPLAY "This cow's udder injuries, udder problems and health problems rank this cow to be in a critical health management situation.";

RULE H19
IF Mastitis=No AND Injury_U=Yes AND Udder_Prob=Edema OR Udder_Prob=Slow_Milker OR Udder_Prob=Broken_Udder_Support AND Influence_Health=None AND Type=Injuries OR Type=Poor_Type OR Type=Poor_Behavior OR Type=Other OR Type=Feet_&_Leg OR Type=Two_or_more
THEN Suggestion=Latent_Cull
DISPLAY "This cow's udder injuries and other problems rank this cow to be in a critical health management situation.";

RULE H20
IF Mastitis=No AND Injury_U=Yes AND Udder_Prob=Edema OR Udder_Prob=Slow_Milker OR Udder_Prob=Broken_Udder_Support AND Influence_Health=None AND Type=None
THEN Suggestion=Potential_Cull
DISPLAY "This cow's udder injuries and udder problems rank this cow to be in an undesirable health management situation.";

RULE H21
IF Mastitis=No AND Injury_U=Yes AND Udder_Prob=Two_or_more AND Influence_Health=Two_or_more OR Influence_Health=Milk_Fever OR Influence_Health=Downer_Syndrome OR Influence_Health=Infective_Disease OR Influence_Health=Respiratory_Problems OR Influence_Health=Other OR
Influence Health=Ketosis
THEN Suggestion=Health Cull
DISPLAY "This cow's udder-injuries and problems rank this cow as a health related cull.";

RULE H22
IF Mastitis=No AND
    Injury_U=Yes AND
    Udder_Prob=Two_or_more AND
    Influence Health=None AND
    Type=Two_or_more
THEN Suggestion=Health Cull
DISPLAY "This cow's udder-injuries and problems rank this cow as a health related cull.";

RULE H23
IF Mastitis=No AND
    Injury_U=Yes AND
    Udder_Prob=Two_or_more AND
    Influence Health=None AND
    Type=None
THEN Suggestion=Latent Cull
DISPLAY "This cow's udder-injuries and udder problems rank this cow to be in a critical health management situation.";

RULE H24
IF Mastitis=No AND
    Injury_U=Yes AND
    Udder_Prob=Two_or_more AND
    Influence Health=None AND
    Type=Injuries OR
    Type=Poor_Type OR
    Type=Poor_Behavior OR
    Type=Other OR
    Type=Feet & Leg
THEN Suggestion=Health Cull
DISPLAY "This cow's udder-injuries and problems rank this cow as a health related cull.";

RULE H25
IF Mastitis=No AND
    Injury_U=Yes AND
    Udder_Prob=No AND
    Influence Health=Two_or_more AND
    Type=Two_or_more
THEN Suggestion=Health Cull
DISPLAY "This cow's udder-injuries and problems rank this cow as a health related cull.";

RULE H26
IF Mastitis=No AND
    Injury_U=Yes AND
    Udder_Prob=No AND
RULE H27
IF Mastitis=No AND Injury_U=Yes AND Udder_Prob=None AND Influence_Health=Two_or_more AND Type=Injuries OR Type=Poor_Type OR Type=Poor_Behavior OR Type=Other OR Type=Feet_&_Leg THEN Suggestion=Health_Cull
DISPLAY "This cow's udder injuries and problems rank this cow as a health related cull."

RULE H28
IF Mastitis=No AND Injury_U=Yes AND Udder_Prob=None AND Influence_Health=Milk_Fever OR Influence_Health=Downer_Syndrome OR Influence_Health=Infective_Disease OR Influence_Health=Respiratory_Problems OR Influence_Health=Other OR Influence_Health=Ketosis AND Type=Two_or_more THEN Suggestion=Latent_Cull
DISPLAY "This cow's udder injuries and problems rank this cow to be in a critical health management situation."

RULE H29
IF Mastitis=No AND Injury_U=Yes AND Udder_Prob=None AND Influence_Health=Milk_Fever OR Influence_Health=Downer_Syndrome OR Influence_Health=Infective_Disease OR Influence_Health=Respiratory_Problems OR Influence_Health=Other OR Influence_Health=Ketosis AND Type=None THEN Suggestion=Potential_Cull
DISPLAY "This cow's udder injuries and problems rank this cow to be in a poor health management situation."

RULE H30
IF Mastitis = No AND Injury_U = Yes AND Udder_Prob = None AND Influence_Health = Milk_Fever OR Influence_Health = Downer_Syndrome OR Influence_Health = Infective_Disease OR Influence_Health = Respiratory_Problems OR Influence_Health = Other OR Influence_Health = Ketosis AND Type = Injuries OR Type = Poor_Type OR Type = Poor_Behavior OR Type = Other OR Type = Feet & Leg
THEN Suggestion = Latent_Cull
DISPLAY "This cow's udder injuries and problems rank this cow to be in a critical health management situation."

RULE H31
IF Mastitis = No AND Injury_U = Yes AND Udder_Prob = None AND Influence_Health = None AND Type = Two_or_more
THEN Suggestion = Latent_Cull
DISPLAY "This cow's udder injuries and type or management problems rank this cow to be in a critical health management situation."

RULE H32
IF Mastitis = No AND Injury_U = Yes AND Udder_Prob = None AND Influence_Health = None AND Type = None OR Type = Injuries OR Type = Poor_Type OR Type = Poor_Behavior OR Type = Other OR Type = Feet & Leg
THEN Suggestion = Potential_Cull
DISPLAY "This cow's udder injuries and problems rank this cow to be in a poor health management situation."

RULE H33
IF Mastitis = No AND Injury_U = No AND Udder_Prob = Two_or_more AND Influence_Health = Two_or_more
THEN Suggestion = Latent_Cull
DISPLAY "This cow's udder problems and other problems rank this cow to be in a poor
health management situation.

RULE H34
IF Mastitis=No AND Injury_U=No AND Udder_Prob=Two_or_more AND Influence_Health=Milk_Fever OR Influence_Health=Downer_Syndrome OR Influence_Health=Infective_Disease OR Influence_Health=Respiratory_Problems OR Influence_Health=Other OR Influence_Health=Ketosis AND Type=Two_or_more
THEN Suggestion=Latent_Cull
DISPLAY "This cow's udder problems and other problems rank this cow to be in a poor health management situation.";

RULE H35
IF Mastitis=No AND Injury_U=No AND Udder_Prob=Two_or_more AND Influence_Health=Milk_Fever OR Influence_Health=Downer_Syndrome OR Influence_Health=Infective_Disease OR Influence_Health=Respiratory_Problems OR Influence_Health=Other OR Influence_Health=Ketosis AND Type=None
THEN Suggestion=Potential_Cull
DISPLAY "This cow shows some health problems that should be watched.";

RULE H36
IF Mastitis=No AND Injury_U=No AND Udder_Prob=Two_or_more AND Influence_Health=Milk_Fever OR Influence_Health=Downer_Syndrome OR Influence_Health=Infective_Disease OR Influence_Health=Respiratory_Problems OR Influence_Health=Other OR Influence_Health=Ketosis AND Type=Injuries OR Type=Poor_Type OR Type=Poor_Behavior OR Type=Other OR Type=Feet & Leg
THEN Suggestion=Latent_Cull
DISPLAY "This cow's udder problems and other problems rank this cow to be in a poor health management situation.";

RULE H37
IF Mastitis=No AND Injury_U=No AND Udder_Prob=Two_or_more AND Influence_Health=No AND Type=Two_or_more
THEN Suggestion=Latent_Cull
DISPLAY "This cow's udder problems and other problems rank this cow to be in a critical health management situation.";

RULE H38
IF Mastitis=No AND Injury_U=No AND Udder_Prob=Two_or_more AND Influence_Health=No AND Type=None-OR Type=Injuries OR Type=Poor_Type OR Type=Poor_Behavior OR Type=Other OR Type=Feet & Leg
THEN Suggestion=Potential_Cull
DISPLAY "This cow shows some health problems that should be watched.";

RULE H39
IF Mastitis=No AND Injury_U=No AND Udder_Prob=Edema OR Udder_Prob=Slow_Milker OR Udder_Prob=Broken_Udder_Support AND Influence_Health=Two_or_more AND Type=Two_or_more
THEN Suggestion=Health_Cull
DISPLAY "This cow's udder problems and other problems rank this cow as a health related cull.";

RULE H40
IF Mastitis=No AND Injury_U=No AND Udder_Prob=Edema OR Udder_Prob=Slow_Milker OR Udder_Prob=Broken_Udder_Support AND Influence_Health=Two_or_more AND Type=None-OR Type=Injuries OR Type=Poor_Type OR Type=Poor_Behavior OR Type=Other OR Type=Feet & Leg
THEN Suggestion=Latent_Cull
DISPLAY "This cow's udder problems and other problems rank this cow to be in a critical health management situation.";
RULE H41
IF Mastitis=No AND
   Injury_U=No AND
   Udder_Prob=Edema OR
   Udder_Prob=Slow_Milker OR
   Udder_Prob=Broken_Udder_Support AND
   Influence_Health=Milk_Fever OR
   Influence_Health=Downer_Syndrome OR
   Influence_Health=Infective_Disease OR
   Influence_Health=Respiratory_Problems OR
   Influence_Health=Other OR
   Influence_Health=Ketosis AND
   Type=Two_or_more
THEN Suggestion=Latent_Cull
DISPLAY "This cow's udder problems and other problems rank this cow to be in a critical health management situation.";

RULE H42
IF Mastitis=No AND
   Injury_U=No AND
   Udder_Prob=Edema OR
   Udder_Prob=Slow_Milker OR
   Udder_Prob=Broken_Udder_Support AND
   Influence_Health=Milk_Fever OR
   Influence_Health=Downer_Syndrome OR
   Influence_Health=Infective_Disease OR
   Influence_Health=Respiratory_Problems OR
   Influence_Health=Other OR
   Influence_Health=Ketosis AND
   Type=None OR
   Type=Injuries OR
   Type=Poor_Type OR
   Type=Poor_Behavior OR
   Type=Other OR
   Type=Feet&_Leg
THEN Suggestion=Potential_Cull
DISPLAY "This cow shows some health problems that should be watched.";

RULE H43
IF Mastitis=No AND
   Injury_U=No AND
   Udder_Prob=Edema OR
   Udder_Prob=Slow_Milker OR
   Udder_Prob=Broken_Udder_Support AND
   Influence_Health=None AND
   Type=Two_or_more
THEN Suggestion=Latent_Cull
DISPLAY "This cow's udder problems and other problems rank this cow to be in a critical health management situation.";
RULE H44
IF Mastitis=No AND Injury_U=No AND Udder_Prob=Edema OR Udder_Prob=Slow_Milker OR Udder_Prob=Broken_Udder_Support AND Influence_Health=None AND Type=None OR Type=Injuries OR Type=Poor_Type OR Type=Poor_Behavior OR Type=Other OR Type=Feet & Leg THEN Suggestion=Potential_Cull DISPLAY "This cow shows some health problems that should be watched.";

RULE H45
IF Mastitis=No AND Injury_U=No AND Udder_Prob=None AND Influence_Health=Two_or_more AND Type=Two_or_more THEN Suggestion=Latent_Cull DISPLAY "This cow's numerous problems rank her to be in a critical health management situation.";

RULE H46
IF Mastitis=No AND Injury_U=No AND Udder_Prob=None AND Influence_Health=Two_or_more AND Type=None OR Type=Injuries OR Type=Poor_Type OR Type=Poor_Behavior OR Type=Other OR Type=Feet & Leg THEN Suggestion=Potential_Cull DISPLAY "This cow shows some health problems that should be watched.";

RULE H47
IF Mastitis=No AND Injury_U=No AND Udder_Prob=None AND Influence_Health=Milk_Fever OR Influence_Health=Downer_Syndrome OR Influence_Health=Infective_Disease OR Influence_Health=Respiratory_Problems OR Influence_Health=Other OR Influence_Health=Ketosis AND Type=Two_or_more OR
Type=None OR
Type=Injuries OR
Type=Poor_Type OR
Type=Poor_Behavior OR
Type=Other OR
Type=Feet & Leg
THEN Suggestion=Potential_Cull
DISPLAY "This cow shows some health problems that should be watched."

RULE H48
IF Mastitis=No AND
Injury_U=No AND
Udder_Prob=None AND
Influence_Health=None AND
Type=Two_or_more
THEN Suggestion=Potential_Cull
DISPLAY "This cow shows some health problems that should be watched.

RULE H49
IF Mastitis=No AND
Injury_U=No AND
Udder_Prob=None AND
Influence_Health=None AND
Type=None
THEN Suggestion=OK_Cow
DISPLAY "The health condition of this cow is satisfactory."

RULE H50
IF Mastitis=No AND
Injury_U=No AND
Udder_Prob=None AND
Influence_Health=None AND
Type=Injuries OR
Type=Poor_Type OR
Type=Poor_Behavior OR
Type=Other OR
Type=Feet & Leg
THEN Suggestion=Potential_Cull
DISPLAY "This cow shows some health problems that should be watched."

ASK Mastitis: "Has this cow had Mastitis this lactation?"

ASK Injury_U: "Has this cow Injured her Teats or Udder in this lactation?"

CHOICES Mastitis, Injury_U: Yes, No;

ASK Udder_Prob: "Does this cow have a broken Udder support, Edema or is slow milking out?"
CHOICES Udder Prob: Broken_Udder_Support, Edema, Slow_Milker, Two_or_more, None;

ASK Influence Health: "Has this cow had any of these health problems?";
CHOICES Influence Health: Two_or_more, Ketosis, Milk_Fever, Downer_Syndrome, Infective_Disease, Respiratory_Problems, Other, None;

ASK Type: "Is this a poor Type, poor behavior, have Feet & Leg problems or had an injury this lactation?";
CHOICES Type: Two_or_more, Feet_&_Leg, Injuries, Poor_Type, Poor_Behavior, Other, None;

RULE E1
IF Projection=Reproductive_Cull AND
FCM<=(Low Val) AND
Suggestion=Potential_Cull OR
Suggestion=OK_Cow OR
Suggestion=Latent_Cull OR
Suggestion=Health_Cull
THEN Recommendation=Cull
DISPLAY "This cow's income is below breakeven and the added reproductive problems suggest you should consider this cow as a reproductive cull.";

RULE E2
IF Projection=Reproductive_Cull AND
FCM>=(Herd Daily$) AND
Suggestion=Potential_Cull OR
Suggestion=OK_Cow OR
Suggestion=Latent_Cull OR
Suggestion=Health_Cull
THEN Recommendation=Delay_Cull
DISPLAY "The reproductive problems suggest you should consider this cow as a potential future reproductive cull.";

RULE E3
IF Projection=Reproductive_Cull AND
FCM>(Low Val) AND
FCM<(Herd Daily$) AND
Suggestion=Potential_Cull OR
Suggestion=OK_Cow OR
Suggestion=Latent_Cull
THEN Recommendation=Delay_Cull
DISPLAY "This cow's income is above breakeven and below herd average, the added reproductive problems would suggest you should remove this cow for reproductive reasons.";

RULE E4
IF Projection=Reproductive_Cull AND
RULE E5
IF Suggestion=Health_Cull AND
FCM>({Herd_Daily$}) AND
Projection=Potential_Rep_Cull OR
Projection=OK_Cow OR
THEN Recommendation=Delay_Cull
DISPLAY "This cow's income is above herd average, health problems should be corrected if possible, they are serious enough to cause the removal of this cow from the herd.";

RULE E6
IF Suggestion=Health_Cull AND
FCM<(Low_Val) AND
FCM>({Herd_Daily$}) AND
Projection=Potential_Rep_Cull OR
Projection=OK_Cow OR
Then Recommendation=Delay_Cull
DISPLAY "This cow's income is above herd average, health problems suggest you should consider this cow as a potential future cull.";

RULE E7
IF Suggestion=Health_Cull AND
FCM<=(Low_Val) AND
Projection=Potential_Rep_Cull OR
Projection=OK_Cow OR
THEN Recommendation=Cull
DISPLAY "This cow's income is below breakeven and below herd average, the added health problems suggest you should consider this cow as a health cull.";

RULE E8
IF Projection=Latent_Rep_Cull AND
FCM>({Herd_Daily$}) AND
Suggestion=Potential_Cull OR
Suggestion=OK_Cow OR
Suggestion=Latent_Cull
THEN Recommendation=Delay_Cull
DISPLAY "This added reproductive problems suggest you should
consider this cow as a potential future reproductive cull.

RULE E9
IF Projection=Latent_Rep_Cull AND FCM>(Low_Val) AND FCM<(Herd_Daily$) AND Suggestion=Potential_Cull OR Suggestion=OK_Cow OR Suggestion=Latent_Cull THEN Recommendation=Delay_Cull DISPLAY "This cow's income is above breakeven and below herd average and the added reproductive problems would suggest you consider this cow a future reproductive cull.";

RULE E10
IF Projection=Latent_Rep_Cull AND FCM<=(Low_Val) AND Suggestion=Potential_Cull OR Suggestion=OK_Cow OR Suggestion=Latent_Cull THEN Recommendation=Cull DISPLAY "This cow's income is below breakeven and the added reproductive problems would suggest you should remove this cow for reproductive reasons.";

RULE E11
IF Suggestion=Latent_Cull AND Projection=Potential_Rep_Cull AND FCM>=(Herd_Daily$) THEN Recommendation=Delay_Cull DISPLAY "This cow's income is above herd average, health and reproductive problems should be corrected if possible to avoid removal of this cow from the herd.";

RULE E12
IF Projection=Potential_Rep_Cull AND FCM<=(Low_Val) AND Suggestion=Latent_Cull THEN Recommendation=Cull DISPLAY "This cow's income is below breakeven and the added reproductive and health problems suggest you should remove this cow for reproductive and health reasons.";

RULE E13
IF Projection=Potential_Rep_Cull AND FCM>=(Low_Val) AND FCM<=(Herd_Daily$) AND Suggestion=Latent_Cull THEN Recommendation=Delay_Cull DISPLAY "This cow's income is above breakeven and below herd average, the added health and reproductive
problems suggest you should consider this cow as a future reproductive and health cull."

RULE E14
IF Projection=Potential Rep Cull AND FCM>(Herd Daily$) AND Suggestion=Potential Cull THEN Recommendation=Possible Cull
DISPLAY "This cow's income is above herd average, health and reproductive problems should be corrected if possible to help this cow avoid removal from the herd.";

RULE E15
IF Projection=Potential Rep Cull AND FCM>(Low Val) AND FCM<(Herd Daily$) AND Suggestion=Potential Cull AND Genetic=GT 0 THEN Recommendation=Delay Cull
DISPLAY "This cow's income is above breakeven and below herd average, the added reproductive and health problems suggest you should consider this cow as a potential future cull."

RULE E16
IF Projection=Potential Rep Cull AND FCM>(Low Val) AND FCM<(Herd Daily$) AND Suggestion=Potential Cull AND Genetic=Not Available OR Genetic=LE 0 THEN Recommendation=Cull
DISPLAY "This cow's income is above breakeven and below herd average, the added reproductive and health problems suggest you should consider this cow as a potential future cull. This cow lacks the genetics of a foundation cow."

RULE E17
IF Projection=Potential Rep Cull AND FCM<=(Low Val) AND Suggestion=OK Cow OR Suggestion=Potential Cull THEN Recommendation=Cull
DISPLAY "This cow is listed as a VOLUNTARY CULL, by removing her from your herd your herd average and income should increase. The true cause of her lower daily income could be due to problems other than genetics.";

RULE E18
IF Projection=Potential Rep Cull AND FCM>(Herd Daily$) AND Suggestion=OK_Cow
THEN Recommendation=Possible_Cull
DISPLAY "This cow's income is above herd average and the added reproductive problems suggest you should try to correct reproductive problems in order to avoid this cow becoming a future reproductive cull."

RULE E19
IF Projection=Potential_Rep_Cull AND
FCM>(Low_Val) AND
FCM<(Herd_Daily$) AND
Suggestion=OK_Cow AND
Genetic=GT_0
THEN Recommendation=Possible_Cull
DISPLAY "This cow's income is above breakeven and below herd average and the added reproductive problems suggest you should consider this cow as a potential future reproductive cull."

RULE E20
IF Projection=Potential_Rep_Cull AND
FCM>(Low_Val) AND
FCM<(Herd_Daily$) AND
Suggestion=OK_Cow AND
Genetic=LE_0 OR
Genetic=Not_Available
THEN Recommendation=Delay_Cull
DISPLAY "This cow's income is above breakeven and below herd average, the added reproductive problems suggest you should consider this cow as a potential future reproductive cull."

RULE E21
IF Projection=OK_Cow AND
Suggestion=Latent_Cull AND
FCM>(Low_Val) AND
FCM<(Herd_Daily$) AND
Genetic=GT_0
THEN Recommendation=Possible_Cull
DISPLAY "This cow's income is above breakeven and below herd average, health problems should be corrected if possible."

RULE E22
IF Projection=OK_Cow AND
FCM>= (Herd_Daily$) AND
Suggestion=Latent_Cull AND
Genetic=LE_0 OR
Genetic=Not_Available
THEN Recommendation=Delay_Cull
DISPLAY "This cow's income is above herd average, health problems should be corrected if possible."

RULE E23
IF Projection=OK_Cow AND FCM>=(Low_Val) AND FCM<=(Herd_Daily$) AND Suggestion=Potential_Cull AND Genetic=GT 0 OR Genetic=Not_Available THEN Recommendation=Possible_Cull
DISPLAY "This cow's income is above herd average, health problems should be corrected if possible. She should be culled for genetic reasons when possible";

RULE E28
IF Projection=OK_Cow AND FCM>(Low_Val) AND FCM<(Herd_Daily$) AND Suggestion=Potential_Cull AND Genetic=LE_0 OR Genetic=Not_Available THEN Recommendation=Possible_Cull
DISPLAY "This cow's income is above breakeven and below herd average and the added health problems suggest you should consider this cow as a future cull."

RULE E29
IF Projection=OK_Cow AND FCM<=(Low_Val) AND Suggestion=Potential_Cull AND Genetic=GT_0 THEN Recommendation=Cull
DISPLAY "This cow's income is below herd average and the added health problems suggest you should consider this cow as a health cull."

RULE E30
IF Projection=OK_Cow AND FCM<=(Low_Val) AND Suggestion=Potential_Cull AND Genetic=LE_0 THEN Recommendation=Genetic_Cull
DISPLAY "This Cow is a true VOLUNTARY CULL. By removing her from your herd your herd average and income should increase."

RULE E31
IF Projection=OK_Cow AND FCM<=(Low_Val) AND Suggestion=Potential_Cull AND Genetic=Not_Available THEN Recommendation=Genetic_Cull
DISPLAY "This Cow is listed as a VOLUNTARY CULL, by removing her from your herd your herd average and income should increase. The true cause of her lower daily income could be due to problems other than genetics."

RULE E32
IF Projection=OK_Cow AND FCM>=(Herd_Daily$) AND Suggestion=OK_Cow AND Genetic=GT_0 THEN Recommendation=Good_Cow
DISPLAY "This cow's income is above average with no reported problems."

RULE E33
IF Projection=OK_Cow AND
THEN \( FCM \geq (\text{Herd Daily$}) \) AND 
\[ Suggestion = \text{OK Cow AND Genetic} = \text{LE 0 OR Genetic} = \text{Not Available} \]

**RULE E34**
\[ \text{IF Projection = OK Cow AND } \]
\[ FCM > \text{(Low Val}) \text{ AND } \]
\[ FCM < (\text{Herd Daily$}) \text{ AND Suggestion = OK Cow AND Genetic = GT 0} \]

THEN Recommendati on=Good Cow 
DISPLAY "This cow's income is above average with no reported problems. She is a genetically inferior cow that might be culled in the future.";

**RULE E35**
\[ \text{IF Projection = OK Cow AND} \]
\[ \text{Suggestion = OK Cow AND} \]
\[ FCM > (\text{Low Val}) \text{ AND}\]
\[ FCM < (\text{Herd Daily$}) \text{ AND Genetic = LE 0} \]

THEN Recommendation=Poss Genetic Cull 
DISPLAY "This cow's income is above breakeven and above breakeven and below average with no reported problems.";

**RULE E36**
\[ \text{IF Projection = OK Cow AND} \]
\[ \text{Suggestion = OK Cow AND} \]
\[ FCM > (\text{Low Val}) \text{ AND} \]
\[ FCM < (\text{Herd Daily$}) \text{ AND Genetic = Not Available} \]

THEN Recommendation=Poss Genetic Cull 
DISPLAY "This Cow is a VOLUNTARY CULL. By removing her from your herd your herd average and income should increase. If you are trying to expand your herd or replacements are scarce, you might consider calving this cow and culling her 100 days into the next lactation.";

**RULE E37**
\[ \text{IF Projection = OK Cow AND} \]
\[ FCM \leq (\text{Low Val}) \text{ AND} \]
\[ \text{Suggestion = OK Cow AND Genetic = GT 0} \]

THEN Recommendation=Cull
DISPLAY "By removing this cow from your herd your herd average and income should increase. The true cause of her lower daily income could be due to problems other than genetics.";

RULE E38
IF Projection=OK_Cow AND FCM<=(Low_Val) AND Suggestion=OK_Cow AND Genetic=LE_0 THEN Recommendation=Genetic_Cull
DISPLAY "This Cow is a true VOLUNTARY CULL. By removing her from your herd your herd average and income should increase.";

RULE E39
IF Projection=OK_Cow AND FCM<=(Low_Val) AND Suggestion=OK_Cow AND Genetic=Not_Available THEN Recommendation=Genetic_Cull
DISPLAY "This Cow is listed as a VOLUNTARY CULL, by removing her from your herd your herd average and income should increase. The true cause of her lower daily income could be due to problems other than genetics.";

ASK Genetic: "What is this cows Cow_Index for dollar value?"
CHOICES Genetic: GT_0,LE_0,Not_Available;

ASK FCM: "What is this cow's current daily value of product?";
Appendix B. Interaction Tree Chart.

<table>
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<tr>
<th>Yield</th>
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Total 132

Possible Decisions
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- Rep_Mast_P
- Rep_Hlth_P
- Prod_Rep_P
- Prod_Hlth_P
- Prod_Mas_P
- Mast_Rep_P
- Mast_Hlth_P
- Prod_Money
- Prod_Rep
- Prod_Hlth
- Prod_Mas
- Mast_Rep
- Mast_Hlth
- Prod_A
- Prod_B
- Prod_C
- Prod_D
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- Prod_G
- Prod_H
- Prod_I
- Prod_J
- Prod_K
- Prod_L
- Prod_M
- Prod_N
- Prod_O
- Prod_P
- Prod_Q
- Prod_R
- Prod_S
- Prod_T
- Prod_U
- Prod_V
- Prod_W
- Prod_X
- Prod_Y
- Prod_Z
## Appendix C. Induction Table.

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Appendix D. Super Expert Prototype of Culling Program.

Cull Cow

Super Expert: Attribute listing
problem: /decision
Yield:
What is the cows current Daily Yield?
Inter the amount in pounds per day (i.e. 60 = 60 lbs. per
day)
%min 0 %max 150

Repro_stat:
Is the cow pregnant or open?
Enter either (1) or (2) depending on cows current
condition.
- Open:
- Preg:

decision:
%clearscreen
This cow, this month is...
- Open High:
... Open with High yield, but still making you money.
%continue

- Preg_High:
... Pregnant with a High yield. Making you Lots of money.
%continue

- Open Avg:
... Open with Average yield...
%chain OPEN_AVG

- Preg_Avg:
... Pregnant with Average yield.
%chain PREG_AVG

- Open_Low:
... Open with Low yield.
%chain OPEN_LOW

- Preg_Low:
... Pregnant with Low yield.
%chain PREG_LOW

- Open_VLow:
... Open and a Very Low yield cow. This cow is costing you
money!!
%chain OPENVLOW

- Preg_VLow:
... Pregnant with Very Low yield.
%chain PREG_VLOW
How many days in milk is this cow?
%min 0 %max 1000

decision:
%clearscreen
This Cow is...
- ProdA:
  ...having production problems serious enough to remove
  her
  from the herd. Remove her as soon as possible!

- Chancecow:
  ...fresh less than 75 days, so we will give her a chance
to
  increase in production. She still could be removed if no
  change occurs!
PregVLow

SCC:
What is the DHIA score for somatic cell counts?
%min 0 %max 9

Health:
The health condition of this cow is...
- Normal:
  ...Normal, meaning she has no added costs for health reasons.
- Question:
  ...Questionable because she had some costs associated with health, but they were under $150 dollars in the past 60 days.
- Expensive:
  ...Expensive, because of her health costs in the past 60 days have amounted to more than $150.

Days Preg:
How many days pregnant is this cow?
%min 20 %max 290

decision:
%clearscreen
This Cow is...
- MONEYCOW:
  ...paying her way and then some.
- Prodmasp:
  ...pregnant, very low producer with mastitis problems. Drastic changes could save this cow, otherwise she will be removed from the herd!
- ProdhltP:
  ...pregnant, very low producer with health problems that could cause her to be removed from the herd if changes aren't made.
- ProdA:
  ...pregnant, but having production problems serious enough to remove her from the herd. Remove her as soon as possible!
- Prodmasa:
  ...pregnant but a very low producer with mastitis problems serious enough to remove her from the herd. She should be removed as soon as possible!
- ProdhltA:
  ...pregnant, very low producer with health problems serious enough to remove her from the herd. She should be removed as soon as possible!
- Prodhltmas:
...pregnant, very low producer that has mastitis and health problems that are serious enough to remove this cow from the herd. Remove this cow as soon as possible!

- ProdhlmsP:
...pregnant, very low producer with health and mastitis problems that could remove her from the herd if changes aren't made soon.
Open-Low

Services:
How many services for this cow?
%min 0 %max 15

SCC:
What is this cows DHIA score for somatic cell counts?
%min 0 %max 9

Health:
The health condition of this cow is...
- Normal:
...Normal, meaning she has no added costs for health reasons.
- Question:
...Questionable because she had some costs associated with health, but they were under $150 dollars in the past 60 days.
- Expensive:
...Expensive, because her health costs in the past 60 days have amounted to more than $150.

DIM:
How many days has this cow been milking?
%min 0 %max 1000

decision:
%clearscreen
This Cow is...
- ProdrepP:
...a low producer with reproductive problems. Drastic changes might save this cow, otherwise she will be removed from the herd.
- ProdmasP:
...a low producer with mastitis problems. Drastic changes might save this cow, otherwise she will be removed from the herd.
- ProdhltP:
...a low producer with health problems that could cause her to be removed from the herd if changes aren't made.
- ProdP:
...having production problems early in her lactation. She might need to be culled.
- ProdrepA:
...is a low producer with reproductive problems that are serious enough to cause her removal from the herd. Remove cow as soon as possible!
- ProdmasA:
  ... a low producer with mastitis problems serious enough to remove her from the herd. She should be removed as soon as possible!
- ProdhlitA:
  ...a low producer with health problems serious enough to remove her from the herd. She should be removed as soon as possible!
- ProdrehltA:
  ...a low producer that has reproductive and health problems that are serious enough to remove this cow from the herd. Remove this cow as soon as possible!
**Preg-Low**

**SCC:**
What is the cows DHIA score for somatic cell counts?
%min 0 %max 9

**Health:**
The health condition of this cow is...
- Normal:  
  ...Normal, meaning she has no added costs for health reasons.
- Questionable:  
  ...Questionable because she had some costs associated with health, but they were under $150 dollars in the past 60 days.
- Expensive:  
  ...Expensive, because her health costs in the past 60 days have amounted to more than $150.

**Days Preg:**
How many days pregnant is the cow?
%min 20 %max 290

decision:
%clearscreen
This Cow is...
- MONEYCOW:  
  ...paying her way and then some.
- ProdmasP:  
  ...pregnant but a low producer with mastitis problems. Drastic changes could save this cow, otherwise she will be removed from the herd!
- ProdhltP:  
  ...pregnant but a low producer with health problems that could cause her to be removed from the herd if changes aren't made.
- ProdP:  
  ...pregnant but having production problems. She might need to be culled.
- ProdmasA:  
  ...pregnant but a low producer with mastitis problems serious enough to remove her from the herd. She should be removed as soon as possible!
- ProdhltA:  
  ...pregnant but a low producer with health problems serious
enough to remove her from the herd. She should be removed as soon as possible!
- **Prodhlmas:**
  ...pregnant but a low producer that has mastitis and health problems that are serious enough to remove this cow from the herd. Remove this cow as soon as possible!

**Open-Avg**

**Services:**
How many services for this cow?
% min 0 % max 15

**SCC:**
What is the DHIA score for somatic cell count?
% min 0 % max 9

**Health:**
The health condition of this cow is...
- **Normal:**
  ...Normal, meaning she has no added costs for health reasons.
- **Questionable:**
  ...Questionable because she had some costs associated with health, but they were under $150 dollars in the past 60 days.
- **Expensive:**
  ...Expensive, because her health costs in the past 60 days have amounted to more than $150.

**DIM:**
How many days has this cow been milking?
% min 0 % max 1000

decision:
%clearscreen
This Cow is...
- **MONEYCOW:**
  ...paying her way and then some.
- **REPHLTP:**
  ...having Reproductive and/or health problems that must be corrected or she will cost you more than she will make you.
- **REPHLTA:**
  ...having Reproductive and Health problems that are costing
you to much to afford to keep her. Remove this cow as soon as possible!
- **REPMASP:**
  ...having Reproductive and/or Mastitis problems that must be corrected or she will cost you more than she will make you.
- **REPMASA:**
  ...having Reproductive and Mastitis problems that are costing you more than she is making you. Remove this cow as soon as possible!
- **REPHLTMASA:**
  ...having Reproductive, Health and Mastitis problems that are costing you money. Remove this cow from your herd as soon as possible.
- **REPHLTMASP:**
  ...having Reproductive, Health and Mastitis problems that are a serious problem. If they are not corrected she might be sold.
- **REPP:**
  ...having reproductive problems. Try to correct them soon.
Preg-Avg

SCC:
What is the DHIA score for the somatic cell counts?
%min 0 %max 9

Health:
The health condition of this cow is...
- Normal:
...Normal, meaning she has no added costs for health reasons.
- Question:
...Questionable because she had some costs associated with health, but they were under $150 dollars in the past 60 days.
- Expensive:
...Expensive, because her health costs in the past 60 days have amounted to more than $150.

Days Preg:
How many days pregnant is this cow?
%min 20 %max 290

decision:
%clearscreen
This Cow is...
- MONEYCOW:
...paying her way and then some.
- Masthltp:
...a pregnant, average producer with mastitis and health problems that could cause her to be removed from the herd if changes aren't made.
- MastP:
...a pregnant average producer with a mastitis problem.
- HlthP:
...a pregnant average producer that is having health problems.
- Masthlta:
...a pregnant average producer with mastitis and health problems serious enough to remove her from the herd.
Remove this cow as soon as possible!
Subproblem-Health

Other:
Has this cow had any other health problems or injuries during the past month?
- Yes:
- No:

Mastitis:
Has this cow had a clinical case of mastitis during the past month?
- Yes:
- No:

Chronic:
Does this cow have a CHRONIC illness?
A chronic illness would be any illness costing over $150 to treat over the past 60 days, include the value of your time.
- Yes:
- No:

Infection:
Does this cow have a reproductive infection?
- Yes:
- No:

Health:
The health condition of this cow is...
- Normal:
  ...Normal, meaning she has no added costs for health reasons.
- Questionable:
  ...Questionable because she had some costs associated with health, but they were under $150 dollars in the past 60 days.
- Expensive:
  ...Expensive, because her health costs in the past 60 days have amounted to more than $150.
VITA
Max L. Checketts
Candidate for the Degree of
Doctor of Philosophy

EDUCATION
PHD - Utah State University - 1991
Emphasis - Genetics and Management
Dissertation - Development and evaluation of an expert
system for use as an aid in culling dairy cattle.

MS in Animal Science - Brigham Young University - 1983
Thesis - Effects of materials and designs used in
inflations: Relative to their durability, porosity,
tissue damage and incidence of mastitis in cattle.

BS in Animal Science - Brigham Young University - 1982

EXPERIENCE
1982 - Present - Ricks College
Member of Animal Science Department Faculty
Responsibilities - Dairy Program, Computer development,
Management course, Nutrition lab, Scheduling.

1979 - 1982 - Brigham Young University
Manager of Dairy Operations
Responsibilities - Milking operations, Labor, Research,
Genetics, day to day operations and student dairy.

1978 - 1979 - Provo Regional Welfare Farm
Responsibilities - Herdsman, milking, breeding & feeding.

PERSONAL
Married          Religion - LDS - Active          Health - Excellent
Interests :Basketball (Height 6'8"), Computers and Family.

ACHIEVEMENTS
1989 - Ag Teacher of the Year
1978 - Served LDS mission to Edinburgh Scotland
1974 - Named to All Region Basketball Team
1973 - Duty to God / Eagle Scout / Runnerup 4H Member/Yr.

PUBLICATIONS
Modern Veterinary Practice. 62:8, pgs. 590-594.
(1985) The influence of inflation composition on udder