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A MODEL FOR EVALUATING ANIMAL HEALTH
MANAGEMENT STRATEGIES
WITH THE COW VIEWED AS A DURABLE ASSET

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A MODEL FOR EVALUATING ANIMAL HEALTH MANAGEMENT STRATEGIES WITH THE COW VIEWED AS A DURABLE ASSET

By

Peter K. Ngategize

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ABSTRACT

A Model for Evaluating Animal Health Management Strategies With the Cow Viewed as a Durable Asset.

by

Peter K. Ngategize

There is a growing concern among livestock farmers over animal diseases that reduce production efficiency. The impacts of diseases like cystic ovaries, metritis and mastitis are not as great as those that cause mortality but the cumulative effect can contribute significantly to the survival of the farm businesses in the existing competitive economic environment. Along with this concern is the increasing availability of alternative management strategies and treatments for such diseases. The ability of decision makers to measure the economic impacts of the diseases that reduce production efficiency and to evaluate the economic consequences of alternative management strategies is becoming a crucial element in the dairy industry. This study was an attempt to address the two issues: (1) to improve the decision making process of farmers regarding animal health strategies and (2) to develop quantitative tools that are adaptable to decision making processes in animal health economics.

The study reviews statistical and economic models that have been used in the evaluation of the economic impact of animal diseases on production. Integration of decision analysis and simulation that utilizes dynamic programming is identified as an appropriate conceptual framework for evaluating the economics of animal diseases that reduce production efficiency. The cow was modeled as a durable asset reflecting the continuous flow of costs and benefits over her entire lifespan.

The model was developed using a Fortran computer code and run on a mainframe computer. Sources of data included secondary and primary data

sources including the Food Animal Health Resource Management System (FAHRMX) database, Today's Electronic Planning (TELPLAN) and Today's Electronic Farm Accounting (TELFARM) databases. A case study of cystic ovaries was analyzed using the model. The results showed that it is more economical to treat cystic ovaries than not to treat. As expected, lactations 4 and 5 are the optimal lactations for keeping dairy cows on the farm business. If treated, the Gonadotropin Releasing Hormone (GNRH) was superior to treatment with the Human Chrionic Gonadotropin (HCG) and no treatment (NT), hence relying on spontaneous recovery. The model was also used to evaluate other factors such as the cost of extending the length of the calving interval.

DEDICATION

To all those, living and dead, who fought for the restoration of human dignity in Uganda during the period of my stay at Michigan State University (1981-1986).

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I am also grateful to the Ford Foundation, Michigan State University, Makerere University (Uganda) and Sage Foundation for their support during my studies at Michigan State University.

I benefited from the company and friendship of many individuals including the Kwesigas, the Byamugishas, the Kaneenes, Rev. Fr. P. Tibanyendera, I. Minde, P. Kaumbutho, O. Aworuwo, Guegbeh Peal, Ruby Frazier and Adrena Pringle. My wife, Peninah and son, Brian persisted through the most trying moments and provided a peaceful atmosphere at home, they deserve my sincere appreciation and love.

Daune Powell deserves special mention for a lot of the typing and assistance that she provided while serving as Dr. Stephen Harsh's Secretary and Pat Neumann for typing the final form of the dissertation.

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CHAPTER I

INTRODUCTION

1.1 Background:

In recent years the dairy industry has been experiencing a trend of increasing production costs especially feed costs whereas milk prices have increased more slowly or decreased resulting in a cost-price squeeze (USDA, 1984). This demands that for farmers to maintain high net incomes, they have to increase output per unit cost. The government's milk diversion and herd termination programs are an attempt to reduce the amount of dairy products coming into the market so as to maintain high prices for farmers. Reduction of production cost has become an important management factor in farming. In the dairy industry, one potential area is reducing the costs associated with diseases. Although much progress has been made in the last quarter of a century in reducing the prevalence of diseases that cause mortality, there are still significant losses associated with diseases that cause reduction in production efficiency especially in Western countries (Morris, 1969). In response to this, a sub-discipline of animal health economics is evolving to provide economic advice in animal health programs:

> ". . . animal health economics has developed as a scientific and practical approach following the second World War when the veterinary services in many countries succeeded in eradicating most of the major infectious diseases and have become increasingly involved in disease prevention and animal production, and related economic effectiveness." Kouba, 1982 p. 346.

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Webster's New Collegiate dictionary defines a disease as a 'condition of the living animal body or one of its parts that impairs the performance of a vital function.' For dairy animals, impairment can take any of the following forms: mortality, long-term disability, reduced reproductive efficiency, reduced milk production, abortion, long calving interval(s), reduced ability to care for the young, and reduced rate of growth. For any particular disease, the impact of any disease will vary in type or form, duration, and magnitude. There will also be variation in types of management strategies and treatments to combat the disease.

As a consequence, a decision maker (farmer and/or veterinarian) has alternative choices of action to take including:

A) taking preventative measures before the disease occurs.

B) controlling the disease from spreading.

C) attempting an immediate eradication as soon as the disease is diagnosed

D) making a choice of alternative treatments for the disease if immediate treatment is the choice

E) deciding on when to begin treatment.

F) taking no action in the hope for spontaneous recovery or until some economic threshold is reached before deciding on treatment

G) culling the animal from the herd.

Any of the above choices will result in a cost(s) to the decision maker including; 1) disease surveillance to avoid outbreaks, 2) medicine, 3) cost of tools, equipment and housing, 4) veterinarian services, 5) transactions and disposal costs, 6) discarded milk, and 7) time foregone in carrying out the above. Some of these costs will have an impact on other farms or other variables in the economic system like product prices and input prices and hence having externality effects.

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The economic implications of animal diseases have been of great concern in Michigan as they have been in other parts of the world. In 1980, under a five year grant by the Kellogg Foundation, an interdisciplinary cooperative program known as the Food Animal Health Resource Management System (FAHRMX) was developed. The project was managed by the department of Large Clinical Sciences with cooperation from the departments of Animal Science, Agricultural Economics, Cooperative Extension Service and the Agricultural Experiment Service.

FAHRMX is a computerized interactive system that collects animal production, management and financial data with the intent of providing information useful for decision making with regard to animal health and related dairy herd management aspects (Bartlett et al 1985). It was hoped that in time, information would be generated and used by farmers in such away that their decision making process would be more efficient and cost-effective. The result of this would then translate into increased monetary returns that would be an incentive for farmers to participate in the FAHRMX project and to be knowledgeable enough as to gradually be willing and able to pay for the costs of running the project related expenses like personal computers, educational programs and other animal health related aspects. Thus, the Kellogg funding was to be the seed that would generate a program that would be cost-effective and self-sustaining. It was hoped that necessary research grants would be generated based on the initial research findings and identified research problems during the course of the project.

Of importance to FAHRMX are diseases that reduce reproductive efficiency. These diseases include cystic follicles, metritis, ketosis, retained placenta, dystocia, milk fever and mastitis. Cystic follicle and metritis are two of the most important reproductive diseases on Michigan dairy farms. Their potential i

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potential impacts range from changes in the general cow behavior, prolonged calving interval to sterility. The loss of reproductivity will lead to loss of production potential in terms of milk, calves and the costs of maintaining the animal that is not productive on the farm. Monetary losses on U.S. farms are estimated in millions of dollars but there are no generally acceptable methods of estimating these costs.

Cystic Follicle

The disease is characterized by cystic ovarian degeneration leading to failure to ovulate and formation of large cystic follicles, luteal cysts and possible cystic corpus lutea. An ovarian cyst is defined as a palpable fluid-filled ovarian structure with a diameter of 25 mm or greater (Erb and White, 1982). It is believed to be caused by an aberration of pituitary gonadotropin hormone release. This hormone is necessary for ovulation. The disease occurs mainly in the first eight weeks after parturition during the peak of lactation. It is more prevalent in cows especially high yielding cows, than heifers. Among heifers the incidence is higher among those kept for many months without breeding or conceiving. Some studies indicate that there is evidence of heritable predisposition (Erb and White, 1982).

Metritis

Metritis is a disease that causes the inflammation of the muscular and endometrial layers of the uterus. It is characterized by a fetid discharge from the uterus. The uterus is atonic and may become swollen and friable. If untreated, chronic metritis develops and the uterus becomes thick walled and fibriotic leading to sterility.

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Recent studies have shown that metritis is closely associated with retained placenta, abortion and dystocia, and that among other things, causes increased calving intervals (Erb, et al., 1981b).

Disease costs associated with cystic follicles, metritis and similar diseases are likely to go unnoticed by farmers or if noticed the full impact on the farm business may not be well understood. Often farmers may easily appreciate direct costs associated with medicine, veterinary services and loss of milk. However, costs associated with extended lactation and calving periods and replacement of sterile cows can be very detrimental to the farm business. In addition the farmer has to select treatments to use for each disease. A number of drugs are now available on the market for each of the diseases and veterinarians offer a wide range of management strategies often based on their individual experiences. This makes decision making even more complex.

1.2 Problem Statement:

FAHRMX and similar projects, currently have the capacity to provide farmers with information relating to herd inventory, animals to be seen for reproductive examinations, calving lists (calendar), heat prediction, vaccination and comparative statistics. However, they do not have the capacity of providing the farmer with information that can be utilized to predict the possible consequences, in monetary terms, of the occurrence of one or more diseases in the herd and make economically optimal choices from the possible courses of action a farmer could take. Previous attempts to evaluate the impact of diseases like cystic follicles and metritis have lacked the analytical framework necessary to incorporate many variables simultaneously and hence have produced erroneous results. Most of the studies have used partial time-limited analyses in estimating the costs of diseases. For example, Bartlett et al. (1986) used partial analysis to estimate

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estimate the cost of cystic follicles on a lactation by lactation basis. In this study it is argued that any analytical approach for evaluating the impact of diseases and the associated management strategies have to incorporate the concept that an animal is a durable asset with potential economic returns flowing over a considerable period of time in an irregular manner. Information on returns and costs generated or incurred in the future is never available with certainty for the researcher. Consequently, data has to be generated through simulation by mimicking the costs and returns as they would flow over the time under consideration.

1.3 General Objectives of the Study

The primary objective of the study was to develop an analytical model that can be used in evaluating the economic impact of animal diseases that reduce production efficiency and in assessing the benefits and costs of alternative management strategies.

Specific objectives are:

1) To review the statistical/epidemiological and economic models that have been used in the evaluation of the impact of animal diseases on production.
2) To determine the merits and limitations of decision analysis as an appropriate model in the evaluation of the economic impact of animal diseases on production.
3) To develop an analytical model using decision analysis in conjunction with simulation to analyze flows of a durable asset.
4) To test the usefulness of the model using cystic ovarian disease as a case example.

1.4 Organization of the Study

Chapter I presents the problem statement and objectives of the study. A review of statistical/epidemiological and economic models that have been used in the evaluation of the economics of animal diseases and programs is presented in

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Chapter II. The conceptual analytical framework is developed in Chapter III and an integrated model of decision analysis and simulation is highlighted. Chapter IV presents the analytical model for evaluating the economics of animal diseases and programs. The various subsystems of the model are presented. A case analysis is made with the model using cystic ovarian disease in Chapter V. Sensitivity analysis is conducted on the model results. The summary, conclusions and recommendations arising from the study are presented in Chapter VI. The study is concluded with a list of references, and a Fortran Computer code for the analytical model in the appendix.

1.5 Limitations of the Study:

The major limitation of the study was lack of sufficient data to use in the development of the model. Although the general analytical framework was developed early during the study, its usefulness depended very much on what type of data was available and the current state of knowledge about the subject. Although the model was developed for application in evaluating management strategies for diseases that reduce production efficiency, data was only available on cystic ovaries and this was also sketchy and incomplete. Thus the timing was relatively off by many months. FAHRMX was still installing some computers, developing more software and improving on the data collection and recording methods. As such even the farmers and practitioners that were associated with FAHRMX had not developed judgement on the pros and cons of the project as it was in developmental stages. In most cases no variable relationships could be developed because the data was incomplete or the number of cases were too few for statistical use.

The second limitation closely related to the first was lack of functional relationship and coefficients for the variables that were to be used in the model.

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For example, there is no established relationship on the impact of a disease like cystic ovaries on subsequent lactations. Secondly, there is limited information on the probabilities of death and culling by lactation over time. Some of the data available was cross-sectional data and was not sufficient for purposes of the model.

The third general limitation was a result of the multi-disciplinary nature of the problem. The study had to utilize extensively knowledge from economics, animal science and veterinary medicine, among other disciplines. This demanded that the author had to reconcile a great deal of information, analytical approaches and judgements to produce a coherent and generally acceptable product.

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CHAPTER II

CURRENT USAGE OF EPIDEMIOLOGICAL/STATISTICAL AND ECONOMIC MODELS IN ANIMAL HEALTH PROGRAMS

2.1 Introduction

In order to effectively measure the impact of a disease, one has to be able to identify and measure the effects it has on the animal. This is not a simple task because disease effects: a) are not always obvious and pronounced; b) are influenced by other factors such as management (e.g., nutrition and housing), environment and others; c) have a temporal dimension which adds to the complexity of evaluating their impacts at different stages in time and d) often manifest themselves in a complex way with other diseases. In an attempt to overcome the above problems, different types of statistical, epidemiological and economic models have been developed.

This chapter presents a review of the models that have been used in the area of animal health. The models are reviewed under two headings: 1) models that are essentially used to determine causal relationships and disaggregate disease impact (i.e., statistical/epidemiological models), and 2) models that measure the monetary impact of disease and can be used in evaluating alternative management decisions (i.e., economic models). An attempt is made to highlight recent applications of the respective models in solving or addressing animal health problems and hence provide a starting point for developing an improved analytical approach for evaluating management strategies of animal diseases.

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2.2 Statistical/Epidemiological Models

The models discussed under this category are used to identify the factors that contribute to the development of disease conditions, the magnitude and direction of the contribution, and relationships between diseases and other animal conditions. The most common models in this category include regression analysis, path analysis, discriminate analysis and analysis of variance.

A. Regression Analysis

Regression analysis is a body of statistical methods dealing with the formulation of mathematical models that depict relationships among variables, and the use of their modeled relationships for the purposes of prediction and other statistical inferences (Bhattacharyya and Johnson, 1977). Classical linear regression analysis involves the regression of one or more variables (the explanatory or independent variables) on another variable of interest, the dependent variable. A number of assumptions have to be met for meaningful results (Kennedy, 1979): 1) it should be possible to specify the function with a set of variables and an error (disturbance) term; 2) the expected value of the error term should be zero; 3) error terms have the same variance and are not correlated with one another; 4) independent variables are "fixed" or can be repeated; and, 5) the number of observations are greater than the number of independent variables and there should be no relationship between the independent variables.

Violation of these assumptions would result in problems including multicollinearity, heteroscedasticity, serial correlation, simultaneous equation bias and the like. Fortunately, some correction measures are available if the violated assumption(s) are identified.

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In ordinary regression analysis, both the dependent and independent variables are quantitative (continuous data). However, one may be interested in discrete/qualitative variables. When the independent variables are qualitative, dummy (or indicator) variables having the value of unity or zero are incorporated (Peter and Wasserman, 1974). On the other hand, when the dependent variable is qualitative, special problems of estimation arise and specific models including logit and probit are used in the analysis.

Regression analysis has been and remains an important statistical tool in a wide range of disciplines. In animal health it has been used in assessing the nature of relationships between disease, production and cost variables and in predicting one variable from observations on other variables.

Miller, et al., (1970) used it in assessing the joint influence of month and age of calving on milk yield of Holstein cows. Month and age of calving were found to be significantly associated with milk yield. Shanks, et al., (1981) has used the model in determining the postpartum distribution of costs and disorders of health. It was demonstrated that the largest costs and most disorders were associated with initiation of lactation rather than the period of peak daily milk yield. Mammary and reproductive costs were 71 percent of total health costs in the first 20 days postpartum. Shanks, et al., (1982) also used the model in projecting health costs using postpartum length, milk yield and calving age as the independent variables.

Regression analysis has been used in many other studies; by Olds et al., (1979) in studying the effects of days open on economic aspects of current lactation; in studying the relation of water source to milk and milk fat production (Hird and Robinson, 1982) and in evaluating the micro-economic impact of Mycoplasma meleagridis infection on turkey production (Carpenter, 1983).

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Thorburn et al., (1983) evaluated the effects of herd size, lactation and DHIA participation in Streptococcus agalactiae infected dairy herds using the log-linear model.

B. Path Analysis

The technique is generally a modification of regression analysis that makes it possible to interpret causal-relationships of complex disease situations (Kaneene, 1982). It has been more often used in disciplines like sociology and psychology than in economics or epidemiological analysis. The method attempts to decompose and interpret linear relationships among a set of variables by assuming that: 1) a (weak) causal order among the variables is known, and, b) the relationship among these variables are causally closed (Nie et al., 1975). One then builds paths of these relationships based on observations and knowledge of the system over time. Then the paths are tested to ascertain their significance as in the usual regression models.

Erb et al., (1981) have used path analysis models to investigate causes and effects of dystocia, retained placenta, metritis, cystic follicles and luteal cysts and other variables like age, days dry, calving interval, and animal breed average for milk. Their results showed that animal breed class average, days in milk, and dry period in the previous lactation had little effect on disease. The most important cause and effect relationship among the diseases was retained placenta causing metritis. Excluding dystocia, all of the disease caused increases in calving interval, in animal breed average for milk and days in milk (Erb, et al., 1981). The model has also been used by Burridge, et al., (1977) in New Zealand and by Salman, et al., (1984) to study the contribution of 28 variables to seropositivity of cattle to Brucella abortus in Mexicali, Mexico.

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C. Discriminate Analysis

Discriminate analysis begins with the desire to statistically distinguish between two or more groups of animals. To distinguish between groups, the researcher selects a collection of discriminating variables that measure characteristics on which the groups are expected to differ. The mathematical objective of discriminate analysis is to weigh and linearly combine the discriminating variables in some fashion so that the groups are made to be as distinct as possible. The method attempts to "discriminate" between groups in the sense of being able to tell them apart. This is achieved by forming one or more linear combinations of the discriminating variables. These discriminate functions are of the form:

D_i = $d_{1i}Z_1 + d_{12}Z_2 + \text{---} d_{1p}Z_p$, where D_i = the score on the discriminate function.

d_i = weighting coefficient.

Z_i = standardized values of the p discrimination variables used in the analysis.

Dohoo and Martin (1983) used discriminate analysis to identify disease conditions associated with an increased risk of culling before the 150th day of lactation. They showed that subclinical mastitis was associated with increased risks of culling and of being sold for dairy purposes after day 150. Mastitis, milk-fever, feet and leg problems, teat injuries and respiratory diseases were associated with an increased risk of culling early in the lactation (before day 150 postpartum). No disease conditions were significantly associated with the risk of being sold for dairy purposes early in the lactation.

Erb et al., (1981) used the same procedure in conjunction with regression analysis to investigate production variables and other diseases as causes of disease. Vandergraaff (1979) used discriminate analysis to study salmonellosis. He attempted to differentiate between affected and non-affected farms and to id

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identify the most important environmental and host factors contributing to group separation. Habtemarium, et al., (1986) used discriminate analysis in classifying regions into high or low risk areas with respect to trypanosomiasis-tsetse problem. His results showed that presence of forest areas, human population density per cultivated hectare and presence of the fusca group of tsetse all contributed significantly to regions being high of risk to trypanosomiasis. This provides, therefore, information essential for planning disease control activities.

Discriminate analysis has value in producing not only information about factors which influence the occurrence of a disease, but it also can be used to locate and deal with "high risk" animals with special cost-effective measures (Morris, 1979).

D. Analysis of Variance

Analysis of variance, like regression analysis, is a versatile statistical tool for studying the relation between a dependent variable and one or more independent variables. It does not require making assumptions about the nature of the statistical relation nor does it require that independent variables be quantitative. The procedure differs from regression analysis in that: 1) the independent variables in analysis of variance models may be qualitative (e.g., sex, geographical location, etc.); 2) if the independent variables are quantitative, no assumption is made about the nature of the statistical relation between them and the dependent variable. Therefore, the problem of specifying the function does not arise. Thus, when the independent variables are qualitative, there may be no choice between regression analysis and analysis of variance. However, when the independent variables are quantitative, the choice of the analysis technique involves one that requires the specification of the nature of the statistical relation (regression) and one that does not require it (analysis of variance). If there is doubt about the nature of the statistical relation, it may require one to use the analysis of variance model to study the effects of the independent variables on the dependent variable without restrictive assumptions on the nature of the statistical relation and then turn to regression analysis to exploit the quantitative character of the independent variable (Peter and Wasserman, 1977).

Sandals, et al., (1979) used the analysis of variance technique to study the effect of retained placenta and metritis complex on reproductive performance in dairy cattle. They found that retained placenta alone did not significantly impair reproductive performance. However, metritis complex, in the presence or absence of retained placenta, caused significant ($P \leq .05$) increase in days open, services per conception, calving to first heat intervals and days open to first service. There was an indication (interaction $P \leq .01$) that cows with both retained placenta and metritis complex are more severely affected than cows with either retained placenta and metritis complex alone.

Muller and Owens (1974) studied the factors associated with the incidence of retained placenta and its influence on subsequent milk production and reproductive parameters. Their findings were: 1) incidence of genital infection was higher in cows with retained placenta, although subsequent breeding efficiency was similar for all cows; 2) milk and fat production were higher for cows with retained placenta; and 3) sex of calf had no influence on the incidence of retention or any of the variables.

E. Time Series Analysis

Data collected over adjacent periods of time, say monthly, quarterly, or yearly, can be useful in making forecasts and predictions about future occurrences of the event in question. Time series analysis is an approach which is used to measure the pattern and characteristics of data that have been observed over tim

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time. Data that are collected over time about an event tend to show or follow certain characteristic patterns or trends or be irregular. In epidemiology, contagious and endemic diseases tend to follow cyclical, seasonal or trend patterns over time. Identification and measurement of these patterns can be useful in the treatment and control of the diseases and in making evaluations and planning projects.

Peralta, Carpenter and Farver (1982) used time series analysis to determine the pattern of foot and mouth disease (FMD) in cattle in Paraguay. The initial hypothesis was that FMD shows cyclical and seasonal behavior that may be related to: 1) virus mutation; 2) density of susceptible; 3) infectivity; 4) contact rates; and 5) duration of sickness and resistance. Results showed that FMD exemplified seasonal and cyclical fluctuations with very slight but significant ($P \leq .05$) increase (trend) over the years 1972-1979. The implications of the results were that: 1) there are certain months when the incidence of the disease is relatively higher than in other months; 2) there is a cycle of 3-4 years over which the same behavior is repeated; and 3) the disease will persist, due to the positive trend component, under the existing circumstances. There was a suspicion, however, that the observed seasonal variation could have been due to vaccination programs which would allow for close contacts with animals and hence more cases of FMD would be reported during the vaccination months than otherwise. This is an indication that one needs to have a clear knowledge of institutional and social circumstances under which the data are collected.

2.3 Economic Models

After the causes of a disease have been identified, the diseases effects disaggregated and quantified, then the next step is to attach monetary values to

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the quantified impacts. The important problems at this stage include: 1) determination of the categories of costs and benefits to include in the analysis; 2) choosing the appropriate prices for the categories; and 3) choosing a discount rate for impacts and categories that flow over time. A detailed discussion of these aspects is covered by Gittenger (1981), Little and Mirrles (1974) and other economic textbooks.

The economic models provide answers to these questions: 1) what are the monetary losses associated with the disease? 2) what are the monetary losses and returns associated with a disease situation and the cost of control measures against the disease?; and 3) what level of disease control is economical or optimal. Answers to the above questions help determine: 1) the level of disease impact with a given control measure; 2) the best alternative control measure; and 3) the optimal combination of alternative control measures.

A. Equi-marginal Principle

This is a very common economic principle in situations where it is desired to determine the optimal level of resource (or input) used in a production process (Harsh, et al., 1981). The principle states that in the allocation of a resource (or input) in a production process, the usage of the resource (or input) should be increased up to the level where the cost of an additional unit of the resource equals the earnings or returns from the additional output due to the additional input. In other words, the optimal allocation is the point where the marginal factor cost equals the marginal value of the product. Similarly, it is not economical to pay for something unless its value is more than the expenditure one incurs at the margin. Carpenter and Howitt (1982) used the same principle in developing a model for evaluating the subsidization of governmental animal dis

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disease control programs. The principle, however, is difficult to operate in practice due to the fact that inputs and outputs may not be divisible in use.

B. Partial Budgeting (P B)

A partial budget is a description of the economic consequences of a specific change in farm procedure. A partial budget is typically made up of four sections: 1) additional revenue realized from the change; 2) reduced costs as a result of the change; 3) revenue foregone as a consequence of the change; and 4) extra cost incurred due to the implementation of the change (Harsh, et al., 1981).

In this context, the change may be a disease preventive program or a new breeding method (e.g., artificial insemination). So long as the elements in each section can be identified, then the decision rule is to adopt the change if the sum of (1) and (2) is greater than that of (3) and (4). As with other models, it is not always possible to identify clearly the costs and returns associated with the change in question. Secondly, many decisions may be rejected or accepted based on other criteria, plus the fact that the partial analysis may not necessarily blend into the total farm strategy (Harsh et al., 1981).

C. Benefit-Cost Analysis

This analytical procedure has been widely used, especially in agricultural projects. It is used in situations where it is desirable to justify the financing of a project based on economic grounds or where a choice has to be made between alternative projects competing for the same funds. There are four main elements involved: 1) enumeration of benefits and costs; 2) determination of the appropriate discount rate; and 3) specification of a decision criteria (usual choice being between Net present value, Benefit cost ratio, and Internal rate of return) and 4) sensitivity analysis (James and Ellis, 1979).

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One variant of benefit-cost analysis is cost-effectiveness. This approach is used when assessing the impact of a strategy or project where the benefits cannot be computed directly. For example, an extension program may be evaluated by how many people adopted the new innovation, in terms of the cost per family that adopted (Erb, 1984). Thus, preference is given to a program that, given its cost, will benefit a greater number of the target population. Projects like Foot and Mouth disease surveillance tend to be evaluated in this manner (McCauley et al., 1979). Bech-Nielson et al., (1983) evaluated control programs for the cattle nematode, Parafilaria bovicola using the benefit-cost technique. Habtemarium et al., (1983) evaluated the cost-effective and benefit maximizing strategies for controlling trypanosomiasis using net prevent values (NPV) and benefit-cost ratios as the selection criteria.

D. Decision Analysis

This technique is becoming essentially useful in the veterinary field (Morris, 1969; Erb, 1980; White and Erb, 1982; Madison et al., 1984). It provides a mechanism for describing complex problems in an explicit fashion, identifying the available courses of action, assessing the probable outcomes and their monetary values, and making simple calculations to select the optimal choice. In the veterinary field, practitioners often use some established protocol, that is, standard methods and rules of procedure for a given clinical situation (Kassirer, 1976). With complex situations the human mind requires a framework for incorporating a large amount of information and selecting among a number of possible alternatives. One such framework is a decision tree. A decision tree is defined as "a graphical method of expression, in chronological order, the alternative actions available to the decision maker and the choices determined by change" (Hillier and Lieberman, 1980).

The first step is to arrange the problem that must be solved and characterize the information needed to make the decision in a structure resembling a tree. In the decision tree, choices such as whether or not to treat, are represented by squares called decision nodes. Chance events or states of nature such as response to treatment are represented by circles called chance nodes. Lines, or branches, follow each node and lead to the next event. The branches following each decision node must be exhaustive; that is, they must include all possible outcomes, and the outcomes must be mutually exclusive.

After each chance node, there is a probability that an event occurs. Here, too, there must be a branch for each outcome, and the branches must be exhaustive and mutually exclusive. The probabilities following a chance node must add up to 1.00. These probabilities can be taken from literature, experimental data, or expert opinion, including the opinion of the person creating the tree if no other source is available (White and Erb, 1982).

The expected outcome, usually monetary, is entered at the far right of the tree branches. Decision is then usually based on some criteria like the minimax, maximax, expected monetary value or expected utility (Fleisher, 1983). White and Erb (1982) have used the technique to analyze decisions related to treating or not treating cystic follicles and when to treat for various days postpartum. The shortcomings of their analysis will be addressed in this study. An extensive evaluation of decision analysis as an analytical framework is made in Chapter III.

E. Linear Programming

This technique is useful in determining the optimal allocation of resources to competing activities. It has been used extensively, especially by farmers with competing enterprises or programs in deciding: 1) what enterprise combinations are ec

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are economical; 2) at what level of operation each enterprise should be maintained or managed; 3) what the expected returns would be from each of the optimal enterprises; and 4) the range of prices over which the particular enterprises would remain economical.

The following requirements have to be met: 1) specification of the objective function, i.e., something that has to be maximized or minimized - this usually takes the form of money (profits or costs); 2) identification of the different enterprises or activities competing for the resources; 3) identification and quantifying of the resource constraints such as money, feeds, medicine, space and the like; and 4) knowledge of input/output coefficients, e.g., weight gain per lb. of feed, yield per cow.

The usual format is of the form:

Objective function:

Maximize $Z = \quad C_j X_j$;

Subject to (constraint):

$A_i X_j = b_i$ and

X_1 — $X_j \quad 0$.

Where

Z = variable being maximized;

C_j = coefficients of payoffs of the activities;

j = activity on enterprise J;

A_{ijs} = input/output coefficients;

b_i = resource constraints i.

The technique assumes linearity in production, divisibility of resources and knowledge of the input/output coefficients. Unfortunately, these assumptions are not usually met in the real world. Therefore, some variants of the technique have been developed to handle situations where some of the assumptions have been violated. These include integer programming, N-stage programming, and separable programming (Hiller and Lieberman, 1980). Application of linear programm

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programming in animal health is still in its early stage. Carpenter and Howitt, (1980) described the use of this model in the turkey industry. Christiansen and Carpenter (1983) used it as a planning tool in the New Zealand Brucellosis evadication scheme. Habtemarium, et al., (1984), used linear programming to evaluate trypanosomiasis control activities in Ethiopia. The objective function included the maximization of net benefits, utilization of unskilled labor, and resettlement of reclaimed land, and decreasing the prevalence of trypanosomiasis from 20% to less than 5% at the end of 5 years. The model constraints were epidemiological, ecological and economic in nature. The results were to be of usefulness in determining the potential optimal use of resources and identifying constraints for long range planning.

F. <u>Markov Chains (Markovian Processes)</u>

This technique is used to study the evolution of certain systems or processes over repeated trials or successive time periods. In epidemiology, Markov chains are simplified and used to make computations where the units under consideration can exist under a number of states, and probabilities can be specified for chances of the units transferring from one state to another.

Therefore, it requires knowledge of the transition probabilities, presented in a matrix form and the numbers (say, animals in each state) presented in a vector form. A crucial assumption is that the transition probabilities are static, that is, we have a steady state (Anderson, Sweeney and Williams, 1980).

The mathematical presentation could be as follows:

$$(S_1, S_2, S_3, S_4)_{to} \quad \begin{matrix} t_{11} \\ t_{21} \\ t_{31} \\ t_{41} \end{matrix} \bullet \begin{bmatrix} t_{12} & t_{13} & t_{14} \\ t_{22} & t_{23} & t_{24} \\ t_{32} & t_{33} & t_{24} \\ t_{42} & t_{43} & t_{44}t \end{bmatrix} = (S_1, S_2, S_3, S_4)_t$$

Where S_1 to S_4 for t_0 represents the number of animals in state one to four respectively in the initial period. The four states could comprise of: 1) susceptible animals, 2) infections, 3) immune, and 4) removed or dead. The t_{ij}'s are probabilities of transfers from state i to state j in a given period. S_1 to S_4 for t_1 represent the number of animals in each state at the end of the first period (iteration). They are the product of vector and the matrix of probabilities. Computations can be done for several periods of time to indicate the proportion of animals in each state at the end of a given period (James, 1977).

Markov chains can also be used to determine what alternative policy to take in processes that repeat themselves over time (Howard, 1960). Ngategize (1982) has used elements of this technique and simulation decision rules to make projects on herd growth over a 15 year period and to compute the costs and benefits of alternative management practices. Markovian programming has been used in cow replacement studies by Giaever (1966), Redman and Kuo (1969) and Ben-Ari et al., (1984). Walker, et al., (1986) have presented a theoretical application of Markov chains in the economic analysis of paratuberculosis (Johne's disease).

G. Systems Simulation

Simulation represents an attempt to emulate real life conditions using simple models over time. It is an attempt to mimic the real world (Morris and Anderson, 1976). It has been used extensively in biological sciences and engineering and economics. As a predictive tool, it can be used descriptively and especially where alternative programs are being evaluated.

In epidemiological studies, simulation has been used by McCauley, et al., (1979) to study the impact of FMD in the United States. Morris and Anderson (1976) used the technique to study the prevalance of mastitis on a monthly basis over a six year period in a herd of 100 cows. The simulated results were utilized to compute: 1) total production of the herd; 2) replacement costs; and 3) cost of control measures.

A similar study has been carried out by Dietrich et al., (1981) to estimate physical losses resulting from alternative bovine brucellosis control programs. The simulation results were used in a benefit-cost analysis to evaluate the control programs.

Rundell (1966) applied simulation to cattle replacement decisions. Morris and Anderson (1976) simulated bovine mastitis. Octanacu et al., (1980) used simulation to study the reproductive process in a herd of dairy cattle. Habtemarium et al., (1983) simulated the effects of various disease-vector control alternatives on the prevalence of trypanosomiasis, and in another study Habtemarium et al., (1983) built a system model to simulate the quantitative epidemiology of trypanosomiasis.

Kliebenstein and Walker (1986) used simulation to estimate economic impact of alternative Johne's (paratuberculosis) control methods in dairy cattle. Control methods evaluated were vaccination of newborn calves, immediate removal of calves from dams at birth with replacements raised separately from the milking herd, and a combination of both. Three disease prevalence rates and the three levels of efficiency of disease control dynamics were evaluated. Vaccination was an effective control method with the three prevalence rates.

H. Dynamic Programming

Most of the models discussed in this chapter are only useful under a given set of assumptions. Some of them already have variants to fit certain situations when one or the other assumption does not hold. Some of the models are so well developed as to have algorithms and packages that are simple to use. Dynamic programming, on the other hand, is a mathematical technique that is adaptable to many complex problems. It is a procedure used for determining the best sequence or combination of decisions in solving complex problems in order to maximize their overall effectiveness (Hiller and Leiberman, 1980). It is a general type of approach that requires a certain degree of ingenuity and insight in determining situations where it is useful and being able to develop the solution procedures. One characteristic is that the complex problem has to be broken into simpler problems that can be solved sequentially. Dynamic programming has been used rather extensively in cattle culling/replacement decisions (Jenkins and Halter, 1962; Smith, 1971; McArthur, 1973; and Stewart et al., 1977). Given the complexity of disease problems and the determination of their economic costs, this technique could be of great potential in providing solutions to complex epidemiological processes.

2.4 Conclusions

The use of models to measure, quantify and evaluate the causal-relationships, impacts and effects of variables on others is on the increase. It is increasingly becoming necessary to defend grant proposals, input use (e.g., chemicals, feeds, machinery) or management practices with numbers that depict monetary value or some other measure as opposed to doing things in terms of protocol or some other subjective criterion. Two broad categories of models have been reviewed.

Models for evaluating causal-relationships and association between variables, especially regression analysis, have been well developed and a wide range of textbooks are available. The second category of models has also been well developed and used, especially in the agricultural economics discipline. They are most useful when one can identify and quantify the different negative and positive effects or impacts of variables on others. Thus, they could be a logical step after using models in the first category.

The choice of any statistical, epidemiological or economic model will depend on a number of factors including: 1) the nature of the disease, host and environment ecosystem; 2) the problem under consideration and the users of the results (e.g., farmer constraints and goals); 3) the resources (time, money, analytical tools available; and 4) the availability of the necessary data and information about the problem.

Advances in the development of Management Information Systems (Davis, 1974) and Decision Support Systems (Keen and Morton, 1978) will enhance the use of the models reviewed. It will, however, demand that the models be refined and appropriate computer software developed to make them more accessible and easy to use by different groups of decision makers in different situations.

CHAPTER III

INTEGRATION OF DECISION ANALYSIS AND SIMULATION AS THE CONCEPTUAL ANALYTICAL FRAMEWORK

3.1 Introduction

In decisions relating to evaluating the economic impact of animal diseases that reduce production efficiency, the basic concept of analysis has to view the cow as a durable asset. This analytical approach recognizes that returns and costs are incurred over time and often in an irregular flow. This also implies that the impact of intervention measures also have to be assessed over the cow's lifespan. The flow of returns and costs as affected by the disease and intervention measures will influence the decisions on optimal cow herdlife and subsequent culling and replacement. The literature review presented in the previous chapter highlighted a broad range of models that are of potential usefulness in the analysis of the economic impact of animal diseases and in evaluating animal health management strategies. However, each model has its' own merits and limitations which have to be assessed before using the model in any specific situation.

The statistical/epidemiological models have been the basis for establishing the cause and effect or association within diseases and between diseases and other variables that arise from management or the environment. For example Bartlett, et al., (1986), have established that there is a strong association between cystic follicles and increased milk production. The parameters derived from this analysis, therefore, are useful as inputs in the overall model of evaluating the economic impact of cystic follicles. Similarly such models have established coefficient estimates on milk yield over time by lactation and season (month of calving). However, these models on their own provide no information for comparing animal health management strategies for decision making purposes.

Economic models are more decision oriented. They are useful in establishing optimal solutions, maximizing returns or merely assessing costs and benefits in monetary terms.

The equimarginal principle is difficult to use operationally due to the fact that some resources are not divisible in use. Secondly often the economic decision is one of optimizing many constraints rather than one resource. Partial budgeting, as the name implies, is only handy in situations where one is dealing with a small part of a bigger enterprise. Thus it assumes divisibility of resource use. Benefit-cost analysis has the advantage of being useful in analyzing the economics of projects (usually agricultural) with the objective of selecting the project that has a higher benefit-cost ratio, net present value or internal rate of return. The analysis assumes that the costs and benefits associated with each project are known. Data limitations are, however, often critical as is the case with the analysis undertaken by this research.

Linear programming also assumes divisibility of resources and knowledge of input and output coefficients. In addition, linear programming, as the name implies, assumes linearity in production. All these assumptions are violated in the problem being analyzed. Dynamic programming and Markov chains also relies on data being available and using a set of algorithms to arrive at the optimal solutions. The option envisioned by this study is to integrate decision analysis and simulation that utilizes dynamic programming as the analytical framework for evaluating the economics of animal diseases that reduce reproductive efficiency.

In the following section decision analysis and simulation are reviewed in detail. Chapter IV will highlight the logic of the analytical model.

3.2 Decision Analysis

Decision analysis is defined as any framework or strategies for handling complex decisions so that they can be more readily evaluated by the human mind (Morris, 1977). A decision analysis of available information is formulated into alternative management decision options. One can consider all economic and statistical/epidemiological models and frameworks used in problem-solving to be part of decision analysis. However, it is more commonly thought to include four techniques, namely: 1) mathematical equations; 2) payoff matrices; 3) process diagrams or process flow charts and 4) decision trees (Morris, 1977).

A mathematical equation is an approach that involves the presentation of data on the decision options, states of nature, probabilities and outcomes in a mathematical form (equation) and using a selected maximizing or optimizing criteria in selecting the action that represents the decision maker's preference. For example, to select among the decision options, $A_1, A_2 \cdots A_i$, information may be presented in the following form;

$$A_i = f\,(A_i, S_1, S_2 \cdots S_j, P_{s1}, P_{s2}, \ldots, P_{sj}, V_{s1}, V_{s2} \cdots V_{sj}).$$

where A_i = Decision options (actions)
P_{sj} = Probability of occurrence of state of nature, S_j
S_j = States of nature
V_{sj} = Value of outcome for each state of nature, S_j

Assuming that one desires to use the expected value (EV) as the decision criteria, then the EV for each action (A_i) would be; $EV(A_i) = \sum_{j=1}^{n} P_{sj} V_{sj}$. Then the action with the highest EV would be selected.

A payoff matrix is a tabular presentation of data on the decision actions (as presented above) giving a better visual presentation of the data. The presentation of the data could take the following tabular form:

Then using some decision criteria, a visual or mathematical computation is made to select the preferred action (Davidson et al., 1981).

Table 3.1. A Payoff Matrix

State of Nature (Sj)	Value of Outcome (V_i) for different action choices (A_i) A_1	A_2....	A_i	Probability of occurrence (P_j)
S_1	V_{11}	V_{21}	V_{i1}	P_1
S_2	V_{12}	V_{22}	V_{i2}	P_2
..	..	..	..	..
..	..	..	..	..
..	..	..	..	..
..	..	..	..	..
..	..	..	..	..
S_j	V_{1j}	V_{2j}	V_{ij}	P_i

A process diagram or flow chart is a technique in which the problem in question is presented in a dynamic sequence of events, information flows, information processing steps, and decision making steps (Morris, 1977). This approach is used in computer programming and is gaining ground in diagnostic work and areas of artificial intelligence. In diagnostic work, the different stages of the flow chart are the procedures that one goes through in identifying a specific disease. Thus by answering questions related to the symptoms of the disease and falling through "yes" and "no" arrows one ends up at a point where a particular disease has been defined.

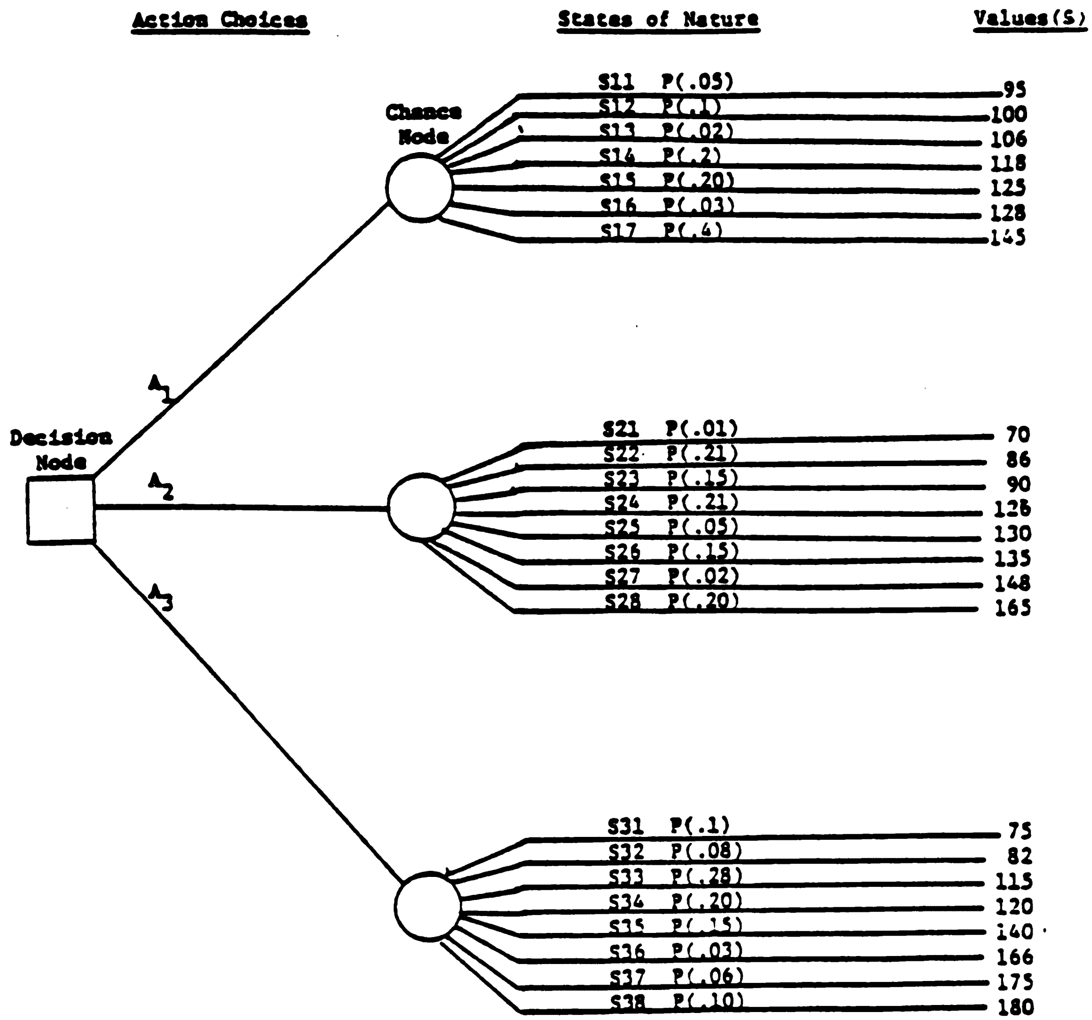
Decision-tree analysis is probably the most frequently used technique of decision analysis (Morris, 1977) and is the subject of the remainder of this paper. Using graphical representation, it shows, in chronological order, the alternative actions available to the decision maker. These originate from a square decision node as branches of the decision tree. Each alternative action is followed by possible occurrences determined by chance, states of nature. These originate from circular chance nodes (Figure 3.1). Associated with each state of nature is a probability of occurrence for the state of nature and the value of the outcome, usually monetary, associated with the action choice and the state of nature (Hiller and Leiberman, 1980; Dohoo, 1984).

Decision-tree analysis had its earliest application in fields like military planning, economics, and marketing (Raiffa, 1968; Hammond, 1967; and Brown, 1970). There is growing literature geared at promoting the use of the technique in human medicine (Lusted, 1971; Tanshoff and Feinstein, 1976; Pauker and Kassirer, 1978, 1980; Weinstein and Fineberg, 1980). It has been applied in the management of coronary artery surgery (Pauker, 1976), renal failure (Pliskin, 1975), heart disease, blood disorders, ulcers, tumors of the bone, headache, abdominal emergency (Anderson and Boyle, 1968), and cancer (Henschke et al., 1967). In animal health management, decision-tree analysis has been used in managing dairy calf mortality (Martin and Wiggins, 1973; White et al., 1983), cysticercosis (Willadsen, et al., 1980), poultry health program design (Carpenter, 1981), cystic ovaries (White and Erb, 1982), and calf fattening operations (Carpenter and Diklgard, 1982; Davidson et al., 1981). In general though, the use of decision-tree analysis in animal health programs is still minimal, and theoretical concepts and bases for its use are still being developed (Dohoo, 1984; Madison et al., 1984 and Fetrow et al., 1985).

3.3 Potential Applications of Decision-tree Analysis

A decision maker in an animal health management program chooses from many possible actions, such as: taking preventive measures before a disease breaks out; controlling the disease from spreading; attempting an immediate eradication as soon as the disease is diagnosed; choosing among alternative treatments for the disease; deciding on when to administer the treatment; giving no treatment and hoping for spontaneous recovery; waiting until some economic threshold is reached before deciding on treatment; or culling the animal from the herd. The above choices involve some cost to the decision maker. These costs could include: surveillance to detect outbreaks; medicine and drugs; tools, equipment, and housing; veterinary services; transactions and disposal costs; labor; discarded milk; reduced genetic potential from the herd; and decreased production.

Decisions pertaining to health programs require that one account for many different components (e.g., states of nature, outcomes, and probabilities) in a meaningful and simple way that facilitates selection of an appropriate choice of action. Often the outcomes of any given action, management strategy, or treatment option are not certain. At the most, one can only establish some probability that a particular outcome will occur. These probabilities also have to be incorporated in the decision-making framework. Decision-tree analysis allows for the incorporation of such information.



Where:

A_1, A_2, A_3 are three alternative action choices

S_1, S_2, S_3 are states of nature under each action choice with the associated probabilities (P).

Figure 3.1: A Hypothetical Decision-Tree Representing Three Action Choices, Associate States of Nature, Probabilities and Monetary Values.

3.4 Merits of Decision Analysis

The use of decision analysis in animal health management programs would have the following benefits:

1) Ease in comprehending and formulating problems using the decision-tree framework. The need to structure the problem into a decision-tree helps identify the logical sequence and important components of the problem. Further, the tree structure can be a useful tool in teaching, extension and education. On its own, the tree structure represents a visual aid, a model, and an algorithm.

2) Flexibility in handling animal health problems. One is able to expand the model as additional information becomes available. Likewise, it can be reduced depending on the desired number of potential or viable options to be analyzed. The inclusion of more than one decision node can also allow for the analysis of dynamic problems as opposed to problems of a static nature.

3) Decision making under conditions of uncertainty. One of the most important attributes of decision analysis is that it allows for handling the uncertainty that exists when one can only associate an outcome with a probabilistic distribution function.

4) The use of decision analysis will enhance the on-going search for appropriate analytical approaches. The need to derive probabilities and outcome values induces the researcher to collect precise information and search for improved analytical tools that may not be readily available.

3.5 Limitations to Using Decision Analysis in Animal Health Programs

Like other techniques, decision analysis has its own limitations.

Time constraint. It tends to require much time and effort. Practitioners tend to resist it, especially where protocols have already been established (Schwartz, 1979). The ability to define a problem and structure it into a practical decision-tree framework will require time and patience, especially where information is limited and the problems to be modeled are complex and/or not fully understood. The time limitation, however, can be overcome in several ways. Developments in computer technology and management information systems, are gradually making information more readily available from a variety of sources in a short period of time. Computers can now build and prune decision-trees quickly and with minimal instructions (Carpenter and Dilgard, 1982). Ready made computer programs like the ARBORIST are now available (Frank, D.W. and Carroll, R. H. 1984).

Derivation of probabilities. Estimates of the probabilities associated with the respective branches are seldom readily available. Often one is left with the option of using subjectively produced probabilities, secondary sources, or conducting separate experiments to generate the relevant information. A number of techniques are available, however, that can be used to derive these probabilities and incorporate them in decision making. Bayesian analysis techniques are useful in deriving revised (posterior) probabilities for the states of nature given new or additional information. Information pertaining to the decision maker's beliefs, experiences, and attitudes toward risk in the form of subjective probabilities (Williamson, 1975) can be incorporated with empirical probabilities. The procedure thus allows for empirical probabilities for events related to the problem to be taken into account in the reformulation of the probabilities of certain outcomes. In addition, sensitivity analysis may be used to test the effect of changing various probability levels on the initial decision.

Sensitivity Analysis is an approach used in evaluating the effects of changing various parameters (probability, benefits or costs) levels on the initial decision. The results show how the selected decision (action) is likely to change with changes in the model parameters; thus, it is used in evaluating the sensitivity of the decision strategy to changes in the probability of the occurrence of the various states of nature (Kassirer, 1976; Madison, et al., 1984).

Alternatively, one may proceed to establish the point in the spectrum of probabilities or outcomes (threshold levels) beyond which the initial decision would not be reversed. This approach is useful for practical purposes, since often one can only estimate the probability range for the model parameters that can be used in selecting the optimal strategy. Thus, at the threshold level one would be indifferent between two or more decision strategies and beyond the threshold point the strategy changes (Pauker and Kassirer, 1978).

Establishing the value of model inputs and outputs. In many instances, the inputs and outputs of a given decision strategy may not have a market value, the market value may not be an appropriate measure, or they may not be tangible or measurable in the usual monetary units (Rahsohoff and Feinstein, 1976). This may, therefore, demand the development of more appropriate measures of value for the input or output in question and the establishment of a common measure of value for evaluating all the inputs and outcomes of a given decision strategy. For example, the market value of a dairy cow may not represent the true or real value of the cow to the farmer. The farmer, among other things, may consider the value of the cow in relation to cattle replacement determinants, such as herd size and his or her goal for herd growth, the availability of replacements, and the genetic potential of the animal. Similarly, it is rather difficult to measure the farmer's liking of a specific animal due to its temperament, beauty, and other intangible attributes.

Uncertainty over the decision criterion. The criterion to use in deciding the optimal strategy may not be obvious. In selecting a management strategy, individuals differ in the type of information they incorporate from the available data set (Fleisher, 1983). The theory underlying the selection process or decision making is known as decision theory.

If the outcomes of every choice were certain and were expressed in some common measure or unit of value, all rational decision makers would most likely make the same choice. Even under conditions of uncertainty, if the outcomes from any one choice and likely states of nature are always more positive than the outcomes of all other choices and states of nature, again the choice becomes obvious. In most cases, however, the probabilities for the various states of nature and their corresponding outcomes may differ. Under such circumstances, unanimity of choice disappears. This is because individuals differ in their willingness to bear the possible consequences of risky events (Robison and Barry, 1984) and in their ability to process data with probabilistic distributions. This difference is attributed to a number of factors including age, level of education, cultural environment and values, level of income/wealth, and acquired skills or experience in the area concerned. Dairy farmers, for example, in making decisions related to animal health, may be influenced by factors such as size of the herd, incidence of a given disease, and goals and objectives in farming.

Given the data presented in Figure 3.1 for example, there are two categories under which we group a number of models that explain the decision criteria that individuals will use to arrive at a final selection of an outcome. There are nonprobability considerations and probability considerations.

Under the nonprobability considerations, individuals disregard the probability associated with the states of nature. One individual may select the action that has the highest value for any of the states of nature regardless of the outcomes on the other states of nature under the action choice. Thus, action three would be selected since the value on state of nature three (A_3, \$180) is the highest for all actions and outcomes regardless of the probability of occurrence. This decision criterion of selecting the action with the outcome of highest value for all the action choices is called the maximax criterion. This reflects a risk-preferring attitude.

Another individual may be concerned with what the lowest likely value is for all actions and their states of nature and make a selection of an action that gives the highest minimum value for all states of nature and action. Hence action one (A_1, \$95) would be selected since it represents the highest of the lowest values for the states of nature of the various action choices. This is called the maximin criterion and thus represents a risk-aversion attitude. Other models that do not incorporate probabilities include the safe-first criteria, lexicographic ordering, and minimax regret (Fleisher, 1983).

With respect to probability considerations, at least three models have been defined. These include the: 1) Laplace decision criterion; 2) expected value criterion and 3) expected utility criterion (for detailed information, see Hiller and Leiberman, 1980; Fleisher, 1983).

The individual who uses the Laplace decision criterion assumes that each state of nature is equally likely and will select that action that has the highest average value (A_3): AV_{A3} = (75+82+115+120+140+166+175+180)/8 = 131.63. Another individual will compute the expected value under each action and select the action that represents the highest expected value (A_1):

$EV_{A1} = P_1$ (value 1) + P_2 (value 2) + P_3 (value 3) + P_4 (value 4) + P_5 (value 5) + P_6 (value 6) + P_7 (value 7) = .05(95) + .1(100) + .02(106) + .2(118) + .2(125) + .03(128) + .4(145) = 127.31.

The third criterion, which is becoming increasingly popular, is the expected utility criterion (Fleisher, 1983). It incorporates the decision maker's utility for income or wealth and his or her attitude toward risk into a preference ordering rule. The expected utility user would assign a utility value to each of the possible outcomes of Figure 3.1. Figure 3.2 shows hypothetical utility values that three individuals, risk averse (RA), risk neutral (RN) and risk preferring (RP) might attach to the monetary values of Figure 3.1.

An important theoretical assumption is made here; that we can derive utility functions and mathematically manipulate the derived utility values and contrast them for the three individuals. For example, for the RA individual, the expected utilities (EU) for the action choice A_1 would be calculated as follows (Halter, et al., 1969, pg. 42):

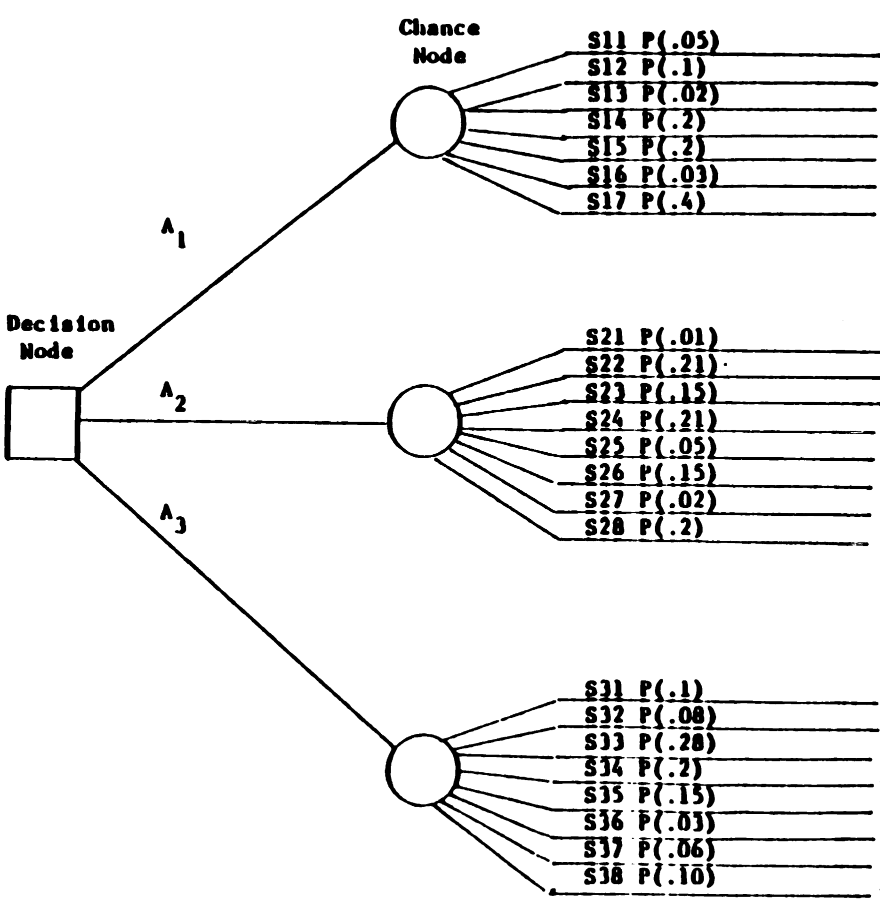
$$EU_{A1}(RA) = P_1 \text{ (Utility 1)}+P_2 \text{ (Utility 2)}+P_3 \text{ (Utility 3)}+P_4 \text{ (Utility 4)}+P_5 \text{ (Utility 5)}+P_6 \text{ (Utility 6)}+P_7 \text{ (Utility 7)} = .05(45) +.1(54) +.02(61) +.2(74) +.2(80) +.03(82.5) +.4(90) = 78.15.$$

The results show that the risk averse RA and risk neutral RN individuals would choose option A_1 while the risk preferring individual RP, based on the highest expected utility for the given action choices, will select option A_3.

The major constraint with this approach is that it is very difficult to elicit the utility functions that are consistent over time and space for individuals (Anderson et al.,., 1977; Robinson, 1982; Amir et al.,., 1984). Derived utility functions are only usable for a short period of time under a given set of circumstances. As an individual's knowledge, income level and attitudes change, the utility functions are likely to change as well.

3.6 Simulation Analysis

As has already been stated, simulation analysis represents an attempt to emulate or mimic real life conditions. It involves the description of the situation under analysis into a problem formulation, developing the problem into a mathematical model which in turn is converted into a computer model. Then the model can be tested, refined and run to generate desired results. Simulation allows for flexibility, adaptability and a problem-investigating process. It can be used to obtain good solutions to problems that are too complex to be solved with procedures like partial-budget analysis, linear programming and others. It's flexibility rests in the building-block organization of the analysis, allowing for the development and incorporation of new components and substitution of simpler components by more complex ones as may be necessary. It also allows the incorporation of a wide range of modelling techniques from different disciplines. It is adaptive in that improved knowledge about data, parameters, and structural relations can be progressively incorporated into the analysis. During the course of model building, a deeper understanding of the system is gained by the analyst and decision maker. Simulation helps raise questions about data collection priorities, structural relationship and behavioral patterns about which theoretical disciplinary knowledge is lacking. Simulation is easy to explain and understand and hence useful for research, extension and policy applications. The merits of simulation analysis will therefore complement those of decision analysis. This will be so especially in as much as simulation will be used to generate some of the data (input and output) that would otherwise be unavailable with decision analysis alone. With simulation data on the flow of returns and costs of a specific animal, given a set of assumptions, will be generated. In addition computer simulation will almost eliminate the time constraint identified with decision analysis due to its speed and accuracy. This will also allow for the ease of conducting sensitivity analysis and adapting the model to different disease conditions.



State of Nature	Monetary Value($)	Expected Value	Associated Utility RA	Associated Utility RN	Associated Utility RP	Expected Utility RA	Expected Utility RN	Expected Utility RP
S11 P(.05)	95		45	20	7			
S12 P(.1)	100		54	24	10			
S13 P(.02)	106		61	29	12.5			
S14 P(.2)	118	127.31	74	40	18	78.15	47.22	24.09
S15 P(.2)	125		80	45	21			
S16 P(.03)	128		82.5	48	23			
S17 P(.4)	145		90	62	35			
S21 P(.01)	70		4	2	1			
S22 P(.21)	86		31	12	4			
S23 P(.15)	90		37	16	5			
S24 P(.21)	126	120.29	80.5	46	22	66.24	42.15	23.05
S25 P(.05)	130		82.5	50	24.5			
S26 P(.15)	135		86	53	27			
S27 P(.02)	148		90	65	37.5			
S28 P(.2)	165		94	79	54			
S31 P(.1)	75		12.5	4	2			
S32 P(.08)	82		25	9.5	3			
S33 P(.28)	115		60	29	12.5			
S34 P(.2)	120		75.5	41	19			
S35 P(.15)	140	124.74	87.5	58	31	66.57	42.9	25.66
S36 P(.03)	166		94.5	80	55			
S37 P(.06)	175		96	87	67			
S38 P(.10)	180		97	91	76			

Figure 3.2: Decision Tree with Three Action Choices, Monetary Values, and the Corresponding Expected Values, Utility and Expected Utility Values for Three Individuals of Different Attitudes Toward Risk

3.7 Some Economic Concepts

The following economic concepts are important for understanding the next chapter in which cost and return flows over different periods have to be analyzed for comparative analysis.

<u>Uncertainty</u>

A decision maker must make decisions about the future even when yields, prices, costs and other factors cannot be predicted with a degree of accuracy. Thus there is uncertainty about such variables. Uncertainty occurs when there is no basis for assigning any probabilities to future events (Harsh, et al., 1981). In situations where the future can be predicted with specified probability distribution (risk situation), the probability distributions can be incorporated in the analysis as has been done with expected value computations in the previous chapter. Lack of probability distributions about future flows and returns represents a management problem. Various approaches have been suggested for use in resolving the problem (Harsh, et al., 1981)

1. One approach to going around the problem is to use higher discount rates for the more uncertain investments. The effect of a higher discount rate being to lower the present value of the benefit for the more uncertain investment. The problem, however, becomes one of determining the appropriate discount rate.

2. The second approach is to use a range of possible outcome associated with each investment alternative. Thus, computation of returns could be made for pessimistic, optimistic and most typical outcomes. As a result one can assess the possible impacts of wide range of likely outcomes.

3. The third approach makes the use of probability theory. This is the most appropriate and commonly used as long as the relevant probabilities can be established. This approach will be used where probabilities can be established.

Discounting:

Since the returns from any given cow are realized at different periods of the cows' lifespan in the herd, discounting becomes important because of the time value of money. "A dollar today is worth more than a dollar tomorrow" because of the time value of money. A dollar earned at the present point in time is worth more because it can be invested and hence earn an interest. A dollar earned at a latter point in time has a lesser value because it will not have earned the interest earned from a dollar that was available at an earlier point in time. For comparison purposes, given earning sources occurring at different points in time the discounting principle is used to establish the present value of earnings raised at different points in time. By putting the future stream of incomes and costs on a current dollar basis then comparisons can be made between alternative income flows. The formula for establishing the present value (V) of a stream of return is:

$$V = \sum_{n=1}^{n} \frac{Rn}{(1+i)^n}$$

where; R_n = amount to be received in future period n.

i = interest rate per time period

n = number of time periods covering the life of the investment.

The formula can also be written as:

$$V = \frac{R_1}{(1+i)} + \frac{R_2}{(1+i)^2} + \frac{R_3}{(1+i)^3} + \text{---} + \frac{R_n}{(1+i)^n}$$

The concept of standardizing or annualizing returns is also an important one and closely related to discounting. The concept enables one to make comparison between alternative income flows overtime. It is significant to know the amount of income an individual would willingly accept to receive today as an alternative to a certain amount of equal incomes over a specified period of time. The equation for computing the annuity factor is:

$$A_n = r / \left[1 - r / (1+r)^{-n} \right]$$

Where A_n = Annuity factor for period i.

r =Interest rate

n =period being considered.

For example, using the discount rate of 12% for a ten year time period the annuity factor is .1770. The interpretation for this is that an individual would be indifferent between receiving .177¢ per year over 10 years and receiving a dollar today. Alternatively if the period of comparison is the same, then the alternative with the highest annuity equivalent would be preferred assuming other things remain the same (e.g. risk of the investment and personal preferences).

Opportunity Cost:

This is a commonly used economic concept. It is based on the knowledge that resources have alternative uses and if resources are employed in one use, say the production of milk, then the resources used are not available for use in other possible production activities like for beef, poultry or hogs. The opportunity cost is the measure of the value of the alternative foregone or sacrificed by not investing resources in the most valuable of the other alternatives. Alternatively, opportunity cost is defined as the maximum net return that is sacrificed because the resource is not employed in its next most profitable alternative (Harsh et al.,. 1981). Resources that are scarce or limit production will have a positive opportunity cost while resources that are not scarce and do not limit production due to their availability or lack of alternative employment opportunities will have a zero opportunity cost. Dairy farmers are concerned with making profits. Profits are often defined as the difference between gross returns and the sum of cash expenses and certain non-cash expenses as depreciation. Accounting profits, however, are defined as the difference between gross cash returns and explicit cash costs associated with a production process. The opportunity cost concept, on the other hand, recognizes that resources have alternative uses and hence in computing profits realized from the use of a resource in one alternative, it is important to also consider the value or returns foregone by not investing the resource in the best of the alternatives where the resource could have been used. The return foregone represents an implicit cost to the alternative in which the resource is being used. This implicit cost has to be put into consideration when computing pure economic profits. Thus an enterprise is said to earn pure economic profit only if the returns from the enterprise exceed the total cost of explicit expenses for inputs purchased and the implicit cost of the net returns from foregone opportunities if the labor and capital were employed in these alternatives.

Other Considerations:

In situations involving the flow of returns overtime, other considerations that need to be addressed include:

(1) Cash purchase versus financing.

(2) Inflation

(3) Taxation effects

Cash Purchase Versus Financing:

In any investment involving a large amount of capital, the investor has to determine whether to use personal funds (if available) or to borrow the funds from another source in which case some interest will be paid on the amount borrowed. Should an individual decide to use personal funds then another cost has to be considered in the form of the potential earnings one would have received if the funds had been put in the bank or invested in another investment. Secondly, investments will have different degrees of risk associated with them. For example, expected earnings on income invested in a savings bank account are more certain than earnings from an investment in a dairy industry due to the uncertainty associated with death, involuntary cull and price fluctuations. The considerations become cricial in choosing between cash purchasing and financing.

Inflation:

Inflation is a rise in the general price level or average level of prices of all goods and services. The general price level thus varies inversely with the purchasing power of a unit of money. Therefore, inflation is also a reduction in the purchasing power of a unit of money. This has the significance of even reducing the value of money at a point in time in the future in a situation of inflation.

Inflation has an impact on investment decision due to its impact on nominal interest rates or the cost of borrowing. Investors acquire capital by paying back the principle and interest that reflects the real return to capital over time (real interest rate) and the expected price increases due to inflation. High inflation results in high nominal interest rates and the high interest rates discourage investors unless the expected rate of return to an investment is relatively high.

Taxation:

Taxation has the effect of reducing an individual's flow of income or wealth. A tax is a compulsory payment usually to government. Most taxes are like an increased cost to the taxpayer and as such influence the flow of costs and benefits in an investment program. Tax laws vary from area to area and from time to time.

3.8 Conclusion:

An integration of decision analysis, and simulation using dynamic programming is chosen as the conceptual framework for analysing the economics of animal diseases that reduce production efficiency and evaluating alternative management strategies. These approaches enhance each other in being flexible, efficient with respect to time and ability to handle situations of uncertainty with respect to the value of model parameters and in arriving at optimal decisions.

CHAPTER IV

THE ANALYTICAL MODEL

4.1 Introduction

This chapter presents the specifications of the model, the data and the model subsystems. A Fortran computer code is presented in the appendix. Figure 4-1 represents a flow chart for the model. The analysis takes the form of an individual cow model as opposed to a herd model. The costs and benefits that flow over the cow's lifespan are simulated over a fourteen year period, the estimated maximum cow lifespan in the herd The model, written in Fortran computer language, was run on an CDC mainframe at Michigan State University.

A number of variables determine the annual income flows from a cow in a herd. These include milk and calf values on the income side and costs related to feeds, labor, health and housing. Given that some of the benefits and costs are fixed relative to whatever animal one is dealing with, a partial analysis involving elements that are variable relative to a specific cow and replacement is used in this model. These variables include (1) milk yield (2) calf value (3) feed costs and (4) health costs.

Milk Yield:

In monetary terms, milk is the most important product from a dairy cow and hence an important indicator of the expected returns from the animal over a period of time. The performance of an animal is measured by milk production, percentage butter fat, calving interval, susceptibility to disease and temperament. These factors are influenced by the genetic potential and the temporary and permanent environmental factors including feed quality, season of calving, milking techniques, lactation number and diseases like mastitis. Prediction of milk yield and related assumptions are made in later sections.

Feed Costs:

Feed is a very important biological factor that has influence on milk production. Feed intake is low immediately after parturition, about 2% body weight. However, consumption increases sharply, peaking about 7-12 weeks post-partum (Jorgnesen, 1977; Hillman, et al., 1973). Peak intake occurs after peak production, usually following within a couple of weeks. Then consumption declines progressively in a linear fashion with milk yield. The relationship ranges between .2 and .07 pounds of dry matter per pound of milk produced (Hlubik, 1979).

Calf Value:

The value of a calf at birth is a function of its (1) sex, (2) genetic potential and (3) physical and health conditions at birth. The genetic potential is the most important factor considered by farmers in selecting calves as herd replacements or purchasing cows and in buying or contracting bulls for artificial breeding.

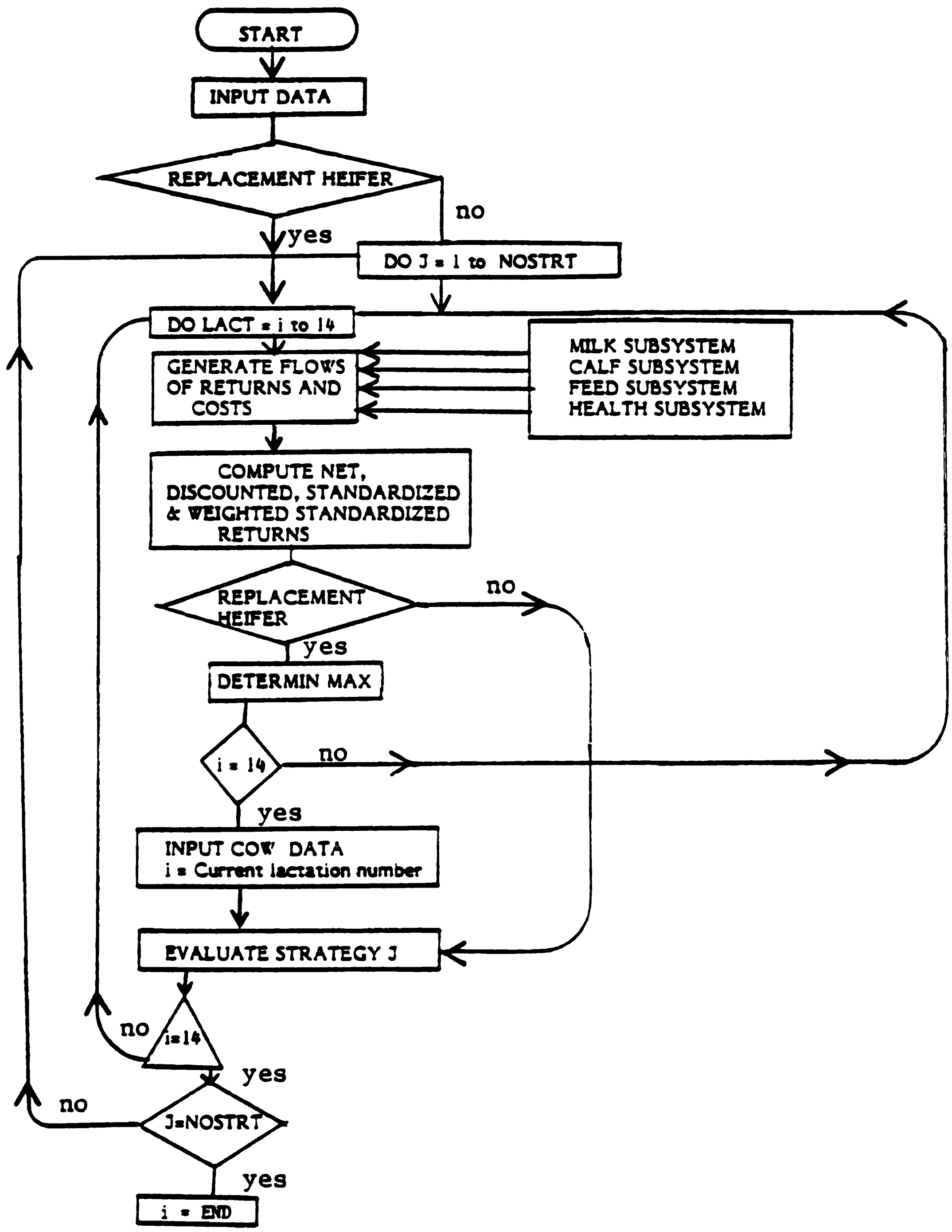
Health Costs:

Health costs are an important component of the model since diseases are the main contributor to the category of health costs. Health costs include direct expenses associated with quarantine, vaccination, chemotheraphy, medical and surgical treatment, examination costs, general labor costs, contaminated milk and replacement costs. Also of significance in this study are indirect costs associated with delayed estrus which causes a delay in the flow of returns from potential milk and newborn calves in future periods and potential costs associated with infertility or sterility. Studies have shown that health costs are generally higher during the early stages of each lactation and decline almost in a linear fashion becoming minimal in the dry period (Shanks, et al., 1981, 1982). These findings are supported by the fact that most diseases like dystocia, retained placenta, metritis, mastitis and cystic ovaries occur early in the lactation. This is the period when the cow is most vulnerable due to the pressure imposed on her by the calf and the potential for infection is higher soon after birth. High producing cows tend to be even more vulnerable and therefore high levels of milk production are associated with high levels of health costs.

4.2 Model Flow Chart:

The model flow chart is presented in Figure 4.1. The model starts with an input of potential replacement heifer data. These data are used by the various model subsystems (milk subsystem, calf subsystem, feed subsystem and health subsystem) to generate the expected flows of returns and costs resulting from milk, calf values, feed costs and health costs over 14 lactations. From these flows discounted net returns are computed over the replacement heifers' lifespan.

The period in which the highest of the weighted standardized returns (standardized returns adjusted for probability of death and cull per lactation. Also see section 4.4.) occurs is used as the optimal replacement period for the heifer. The computed weighted standardized value, called MAX in the flow chart, is compared with the weighted standardized returns for the sick cow to determine whether to keep the sick cow or replace it with the potential replacement heifer. The model also evaluates the economic returns for any given management strategy. Decision criteria for culling or for selecting optimum management strategy are discussed in latter sections.



Where: i = lactation number
J = management strategy counter
LACT = lactation number counter
MAX = highest weighted standardized return over the replacement heifers' lifespan
NOSTRT = number of management strategies

Figure 4.1: Model Flow Chart and Subcomponents

4.3 Simulation Model Subsystems

A. THE MILK SUBSYSTEM:

In this subsystem, total milk production for the lactation is simulated and the returns from the milk produced computed. Milk production (MILK) in a given lactation is a function of

a) milk produced in first lactation (YLDFST)
b) month of calving for current lactation (SEAFAC(MNTH))
c) lactation number for current lactation (LACT)
d) length of lactation (LACLGT).

Therefore, MILK = f(YLDFST, SEAFAC (MONTH), LACT, LACLGT).

YLDFST is based on a normal 10 months (305 day) lactation period. Therefore, to predict the lactation yield in any subsequent lactation, the lactation factor (LACFAC) and seasonal factor (SEAFAC) are used. This gives an expected production (YLDNOW) for a given lactation based on a 10 month lactation length (LACLGT). The true production yield (MILK) is arrived at by adjusting for lactation length. The calculation curves generated by Stallcup et al. (1978) as presented in Table 4.1 were extended using linear extraporation to generate yield for up to a 14 month lactation length (Table 4.2). This extraporation was necessary because some diseases are expected to cause longer calving intervals due to the failure to breed successfully during the time that the cow has the disease.

EXAMPLE:

A cow that produced 14,000 lbs in her first lactation and is now expected to have it's seventh lactation in July, the predicted milk production is

$$YLDFST \times SEAFAC \frac{\text{(Current Month}}{\text{(Month of First Lactation)}} \times LACFAC \frac{\text{(Current Lactation)}}{\text{(Lactation One)}}$$

$$14{,}000 \times \frac{1.0554}{1.0554} \times \frac{.99}{.82} = 14{,}000 \times 1 \times 1.207$$

$$= 16{,}902.8 \text{ lbs.}$$

where:

1.0554 is the seasonal factor (SEAFAC) for the month of July assuming that both the first lactation and the current lactation occurred in July (Table 4.5).

.99 and .82 are the lactation factors (LACFAC) for the seventh and first lactations,respectively (Table 4.4).

The resulting value of 16,902.8 lbs is adjusted by the lactation length for the lactation under consideration to give total yield (MILK) and MILK is used to compute total income from the lactation by multipling total milk production by the unit price of milk. Milk income is the final output of the subsystem MILK.

In order to account for lactations that extend beyond the usual 10 months (305 days), the data generated in Table 4.2 is used. The break down of milk production into lbs. per day helps in extending the lactation periods for cows that are sick resulting in extended calving intervals and also allows for estimating feed requirements on a daily basis for the FEED Subsystem.

Predicting Month of Next Lactation and Subsequent Lactations

Assuming a normal twelve month calving interval, the subsequent lactation starts in the same month as the previous month of calving. If the calving interval is extended by one month to 13 months, then the month of calving shifts one month for the next lactation (i.e. if the first calving occurs in January, the next and the subsequent calvings will occur in February.). If the calving interval is 14 months, the month of calving will shift 2 months for the next and subsequent lactations. It is assumed that the subsequent lactations will have the normal twelve month calving intervals.

B. THE FEED SUBSYSTEM:

Feed requirements for dairy cattle are, among others, a function of:

1. State of the animal (lactating or dry).
2. Level of milk production.
3. Lactation number (1, 2 or more).
4. Size of the animal.
5. Feeding System and feeds.

Today's electronic planning (TELPLAN 31) version 5 (Milligan et al., 1984) was used to generate feed requirements on a daily basis taking into account the variables above. Three tables of feed requirements for a 1st lactating cow, 2nd lactating cow and mature cow (over lactation 2) were generated for milk levels ranging from 100 lbs/day to 30 lbs/day. The weight of animals were 1300 lbs for 1st lactating cow, 1400 lbs for 2nd lactating cow and 1500 lbs for mature cow. The conventional system of feeding was used. The feed requirements in lbs of feed per day per given level of milk production are represented in Table 4.3. The feeds used in formulating the ration were: (1) Alfalfa/hay, valued at $60/ton; (2) Corn silage, at $18/ton; (3) Grain shelled corn at $80/ton and (4) Soybean meal at $140/ton and a premix of micronutrients at $440 a ton.

The feed subsystem follows the MILK Subsystem and uses the generated daily milk production levels from the lactation curves to determine feed requirements per level of production for a given cow. Total feed requirements are accumulated on a monthly basis, multiplied by prices for respective feeds and summed to get feed cost for the lactation. In cases where a disease would have an effect on feed intake, then the feed costs during the period when the cow is sick must be adjusted to reflect the savings on feed costs.

Table 4.1: Milk Production of Cows with Different Production Potential, by Month of Lactation

Group	1	11	111	1V	V
No. of Cows	13	29	15	7	6
Milk Production lb/305 day	14,300	18,400	20,500	22,100	24,800
Production lb/day					
1st month	59.4	72.7	80.2	82.5	95.5
2nd month	60.4	72.2	76.9	84.0	92.5
3rd month	55.4	68.9	71.5	78.2	90.7
4th month	53.2	65.2	70.4	76.1	83.1
5th month	50.2	59.2	62.7	76.8	83.4
6th month	46.1	54.0	61.8	71.0	77.6
7th month	43.3	53.0	60.2	69.7	75.5
8th month	39.2	50.9	57.5	63.6	71.6
9th month	36.7	45.5	52.4	61.0	63.1
10th month	32.1	43.0	51.6	57.0	58.6

Source: Stallcup, O.T., Kellogg, W. D. and Rakes, J.M. "Dietary Protein Requirements for High Producing Dairy Cows." In Dairy Science Handbook, Vol. 16 by Frank H. Baker and Maron E. Miller (Ed.), West View Press, 1984.

Table 4.2: Calculated Milk Production of Cows with Different Production Potential, by Month of Lactation

Production lbs/305 days	14000.	17000.	19000.	21000.	2300.
Production lbs/day					
lst month	58.2	70.5	78.7	80.2	92.5
2nd month	59.2	70.0	75.5	81.7	89.6
3rd month	54.3	66.8	70.2	76.0	87.8
4th month	52.2	63.2	69.1	74.7	80.5
5th month	49.2	57.4	61.5	74.0	80.8
6th month	45.2	52.3	60.7	69.0	75.2
7th month	42.5	51.4	59.1	67.8	73.1
8th month	38.4	49.3	56.4	61.8	69.3
9th month	36.0	44.1	51.4	59.3	61.1
10th month	31.5	41.7	50.6	55.4	56.8
11th month	27.0	39.3	49.8	51.5	52.5
12th month	22.5	36.9	49.0	47.6	48.2
13th month	18.0	34.5	38.2	43.7	43.9
14th month	13.5	32.1	37.8	39.8	39.6

Table 4.3: Feed Requirements for Different Production Levels of Cows in Lactation 1, 2 and Over Respectively

	LBS/MLK/DAY	ALF/HAY	CORN SIL	GR CORN	SOY44	PREMIX
Lact 1	0.0	5.00	39.56	0.00	0.00	0.18
	30.0	5.00	79.65	0.00	0.00	0.38
	40.0	5.00	83.47	2.28	1.07	0.50
	50.0	5.00	76.06	7.34	2.67	0.63
	60.0	5.00	67.38	12.78	4.31	0.76
	70.0	5.00	57.55	18.58	5.98	0.90
	80.0	10.14	33.17	25.90	7.17	1.21
	90.0	12.90	26.06	28.09	8.49	0.99
	100.0	19.40	32.20	25.40	2.50	0.00
Lact 2	0.0	5.00	42.53	0.01	0.00	0.21
	30.0	5.58	76.31	0.00	0.00	0.37
	40.0	10.53	81.00	0.00	0.00	0.35
	50.0	9.83	95.61	0.00	0.77	0.46
	60.0	5.00	101.55	3.83	2.81	0.69
	70.0	5.00	94.37	9.00	4.36	0.82
	80.0	5.00	86.08	14.52	5.95	0.92
	90.0	5.00	76.73	20.37	7.56	1.09
	100.0	6.60	62.07	26.92	9.06	1.20
Lact 3	0.0	5.00	42.53	0.87	0.00	0.24
	30.0	6.60	71.63	0.00	0.00	0.35
	40.0	11.63	75.83	0.00	0.02	0.32
	50.0	14.31	84.53	0.00	0.33	0.35
	60.0	16.87	94.10	0.00	0.59	0.39
	70.0	15.20	106.33	1.17	1.63	0.53
	80.0	5.60	106.33	12.90	3.35	0.70
	90.0	10.28	106.33	10.25	5.12	0.89
	100.0	7.37	106.33	15.10	6.93	1.09

Source: Telplan, Program #31, Version 5.

Table 4.4: Lactation Factors for Estimating
Milk Production Over 14 Lactations

Lactation #	1	2	3	4	5	6	7
Lactation Factor	0.82	0.90	0.96	0.99	1.00	1.00	0.99
Lactation #	8	9	10	11	12	13	14
Lactation Factor	0.98	0.93	0.88	0.82	0.76	0.70	0.64

Source: Adopted from Ted Ferris (1985) Unpublished Research Work, Department of Animal Science, Michigan State University.

Table 4.5: Seasonal Factors for Estimating Production
Levels as a Function of Season (Month) of Calving

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL
Seasonal Factor	0.9627	0.9676	0.9690	0.9814	0.9982	1.0320	1.0554
Month	AUG	SEPT	OCT	NOV	DEC		
Seasonal Factor	1.0542	0.0229	0.9974	0.9814	0.9778		

Source: Hlubik, J. 1979. "An Economic Evaluation and Replacement Model for the Lactating Dairy Cow Including Biological Components." Unpublished MSC Thesis. Michigan State University.

C. CALF VALUE SUBSYSTEM:

One important factor that influences milk production is the genetic potential of the cow. This is also a factor considered by farmers in selecting calves as herd replacements or purchasing cows for dairy purposes and in buying or contracting semen for breeding purposes. One measure of genetic merit is the Estimated Transmitting Ability (ETA) or Cow Index. DHIA data gives the calf's ETA at birth in lbs of milk. Twice the ETA value gives the Expected Breeding Value (EBV) which, when compared to other cows in the herd gives an indication of the expected difference in yield.

Assuming the calf's ETA = 400 lbs, then EBV = 800 lbs. As a cow the best estimate is that she will yield 800 lbs of milk per lactation over her herdmates. This means a higher income of 800 lbs X milk price/lb. during her mature period. The EBV for various lactations are adjusted using the lactation factors (LACFAC) reported in Table 4.4. For each additional yield in milk, there is an increase in demand for food and health costs both accounting for 32% of milk returns. Incorporation of these factors gives rise to an equation developed by Kuipers (1980) which was used in the analysis with some modifications.

CALF = .441* (AVFCP + EXTRA) + 0.459*AVMCP

where CALF is the estimated calf value.
.441 results from a female sex ratio of 49% female,
and 10% mortality
.459 results from a male sex ratio of 51% male and 10% mortality.

AVFCP is the Average Female Calf market Price.
AVMCP is the Average Male Calf market Price.
EXTRA is extra value assigned to a genetically superior heifer calf.
EXTRA = 3.813 *(PRMLK * EBV * LACFAC)* .68.
EXTRA = 0 if Extra   0.

Where:

EBV is the Expected Breeding Value

LACFAC is the factor to adjust the EBV for the lactation under consideration (Table 4.4).

PRMILK is the price of milk per lb.

3.813 is a constant that expresses the expected extra income flow from a live heifer calf (Kuipers,1980).

.68 is the milk return over feed and health costs; 32% of the additional milk returns of a cow is expected to be feed and health costs.

D. HEALTH SUBSYSTEM:

Health costs are modeled as a function of stage of the lactation, level of milk production and direct costs associated with the disease under consideration. The equation for simulating monthly health costs is of the form:

HLTH = 20.0*(1/K) + MLKCOST + DISCOST.

Where:

HLTH = Total health costs per month

20.0 = Average health costs incurred in the first month of lactation.

K = Month number of the lactation including the dry months.

MLKCOST = Extra feed and health costs associated with level of milk production over 15,000 lbs per 305 day lactation (0.32 cents per $1.00 value of milk produced over 15,000 lbs.).

DISCOST = Direct costs associated with the disease under consideration.

4.4 Evaluation of the Management Strategies

The model was built to address the following questions:

(1) Should an animal be treated?

(2) If treated what year is it likely to be culled?

(3) What treatment is most economical?

Decision to Treat:

The decision to treat or not to treat is made by comparing the expected returns over the remaining economical life of a sick cow with the expected average returns of a potential replacement heifer over her optimal lifespan. In order to arrive at this comparison, a sequence of procedures has to be followed:

(1) Establish the optimal herd-life of the potential replacement heifer and the average returns over that period.

(2) Establish the optimal replacement period for the sick cow under the assumption that it recovers after treatment.

(3) Decide whether to cull or not to cull.

(4) If the decision is not to cull, select the optimal treatment to use.

(5) If you decide to cull, determine the period in current lactation in which to cull.

Optimal Herdlife for a Potential Replacement Heifer:

A potential replacement heifer is taken to be a two-year old heifer just before calving with a first lactation level equal to the herd's production average. The longest period that a cow can live in the herd is 14 lactations. Net returns are simulated over the 14 year period, discounted, standardized and weighted for the probabilities of death, voluntary removal and involuntary removal. The highest value of the weighted standardized returns for the voluntary removal option determines the optimal period for keeping the heifer in the herd. This optimal value is used in determining the potential for keeping the sick cow in the herd. The decision criterion is that the sick cow may be kept in the herd if her weighted standardized returns following the desease treatment for remaining lactations are higher than the replacement heifer's optimal value (see Figures 4.2 and 4.3).

Figure 4.2 represents a hypothetical graphical picture of the flow of returns for a potential replacement heifer over four lactations. The solid lines with

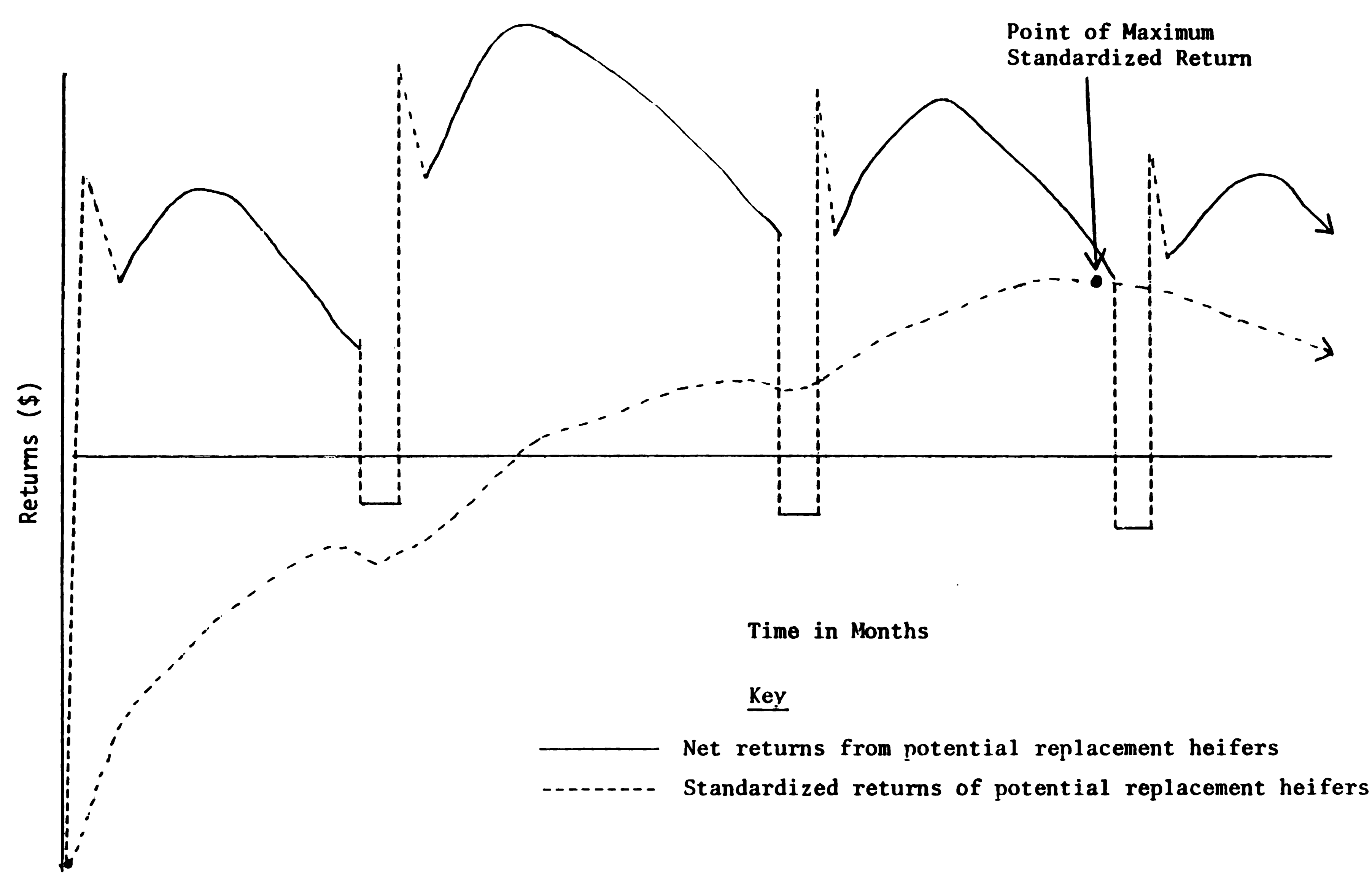


Figure 4.2: Expected Net Returns and Standardized Returns for a Hypothetical Replacement Heifer

dotted areas represents the net flow of returns. This line starts off in the negative region due to the opportunity cost of keeping the heifer for milk production rather than selling her to another dairy operation. Then it jumps up to a high representing a calving point and soon after the solid line represents a flow of positive net returns mainly due to milk production. The solid line cuts off when the cow is dried off and hence the bottom line represents negative net returns mainly due to feed expenses during the dry period. Then the cow calves again and the stream of net returns continue in a similar fashion. Standardized returns from the same cow are represented by the dashed line that starts of negative and has a gradual increase with a few troughs reaching a maximum after the third lactation. These standardized returns are weighted by the probability of death, voluntary cull and involuntary cull over each lactation (Table 4.5 and 4.6). The lactation number with the highest weighted standardized returns represents the optimal lactations the replacement heifer should be kept in the herd and its value will represent the minimal accepted individual lactation weighted standardized return for keeping the sick cow prior to replacement. Thus in Figure 4.3 hypothetical returns for a sick cow are represented as for the replacement heifer. The opportunity cost of keeping the cystic cow is the beef value forgone. Hence, the returns for a cystic cow are also initially negative. The sick cow may be kept on the farm if at some point, her weighted standardized returns over the remaining lactations rise above the highest of the weighted standardized returns for the replacement heifer.

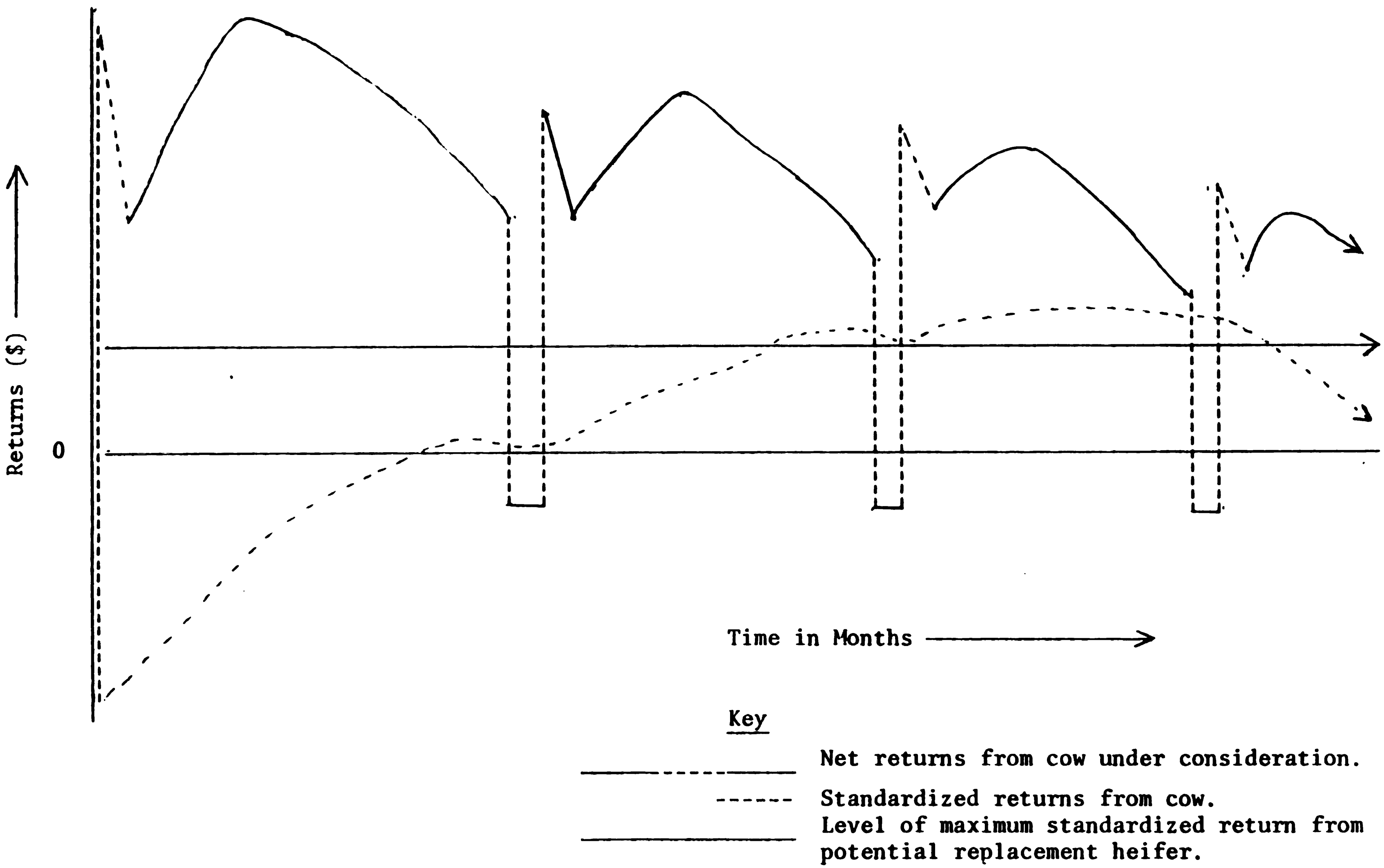


Figure 4.3: Expected Returns and Standardized Returns for a Potential Replacement Heifer and Cow.

EQUATIONS:

(1) $NET_i = Milk_i + Calf_i - Feeds_i - Health_i - Opp\ cost._i$

Where:
- NET = Net returns in month i.
- MILK = Milk returns in month i.
- CALF = Calf value in month i.
- FEEDS = Feed costs in month i.
- HEALTH = Health costs in month i.
- OPPCOST = Opportunity cost (ref. cows market value) in month i.
- i. = month under consideration: i = 1,2,-----N.

(2) $DISNET_i = NET_i * DISFAC_i.$

(3) $ACCUMNET_i = NET_{i-1} + NET_i.$

(4) $STDINCC_i = ACCMNET_i * ANNUITY_i.$

(5) $$WSTDINC_j = (PD * STDINCD) + (PINVC * STDINCC) + STDINCS\,(1 - (PD_{j-1} + PINVC_{j-1}))$$

Where:
- WSTDINC = Weighted Standardized income for lactation j.
- PD = Probability of death in lactation j.
- PINVC = Probability of involuntary cull in lactation j.
- STDINCC = Standardized income, in the event of an involuntary cull in lactation j.
- STDINCCS = Standardized income, in the event of a voluntary cull in lactation j.
- STDINCD = Standardized income in the event of death in lactation j.
- j = Lactation number, J=1,2,-------14.

(6) $$WILSTDINC_j = PD_j * STDINCD_j + PINVC_j * STDINCC_j + STDINCS_j(1-PD_j + PINVC_j).$$

Where:
- WILSTDINC = Weighted individual lactation standardized income.

Probabilities of Death and Involuntary Cull:

The probabilities of death and involuntary cull were derived from the studies by Stewart et al. (1977) and Sol et al. (1984) (Table 4.6). The probability of involuntary cull is defined as the probability of culling a cow due to reproduction failure, disease and other ailments. On the other hand, the probability of voluntary cull is defined as culling primarily due to low production.

A mathematical extrapolation technique was used to extend the probabilities to 14 lactations, the maximum number of lactations allowed for the model purposes. The theoretical basis for the extrapolation was that the probability of death and involuntary cull will increase from lactation to lactation as the animal gets older and hence gets more vulnerable to diseases and other ailments. The extrapolation was done by adding a factor to probability of a previous lactation. The factor was arrived at by taking the average of three previous Interlactation probability differences. For the probabilities of death, they were adjusted downwards to make them more realistic (based on consultation with experts in the industry). The results are presented in Tables 4.7 and 4.8. The probabilities so derived are really cross-sectional in nature. They give the information that there is such a probability that a cow in a given lactation will be culled or die. For the purposes of the model, however, one would be interested in the transition probabilities. For example, the relevant probability for death in a given lactation is the probability that a dairy cow that happen to survive to the lactation will die in that lactation. The probabilities of Tables 4.7 and 4.8 were thus adjusted by considering:

a) the probability of a cow living to a certain lactation.

b) the probability that it dies or is culled in that particular lactation.

The following formula was used in computing the probability of a cow being in a particular lactation.

$$PR_i = 1 - \left(\sum_{j=i}^{n} IC_j + \sum_{j=i}^{n} D_j \right)$$

where: PR_i = Probability of a cow being in lactation i.

D_j = Cross sectional probability of death in lactation j, j=i-1.

IC_j = Cross-sectional probability of involuntary cull in lactation j.

Table 4.6: Probabilities of Involuntary Cull and Death

Lactation	Probability of Involuntary Cull[1]	Probability of Death[2]
1	.018	.118
2	.082	.161
3	.115	.204
4	.13	.247
5	.196	.290
6	.210	.333
7	.301	.376
8	.335	N/A
9	.392	N/A
10	.356	N/A
11	.445	N/A
12	.45	N/A

1 Sol, J. et al., 1984. Veterinary Quarterly 6(3):149-157.

2 Stewart, et. al., 1977. J. of Dairy Science 60:602-617.

With the PR_i's computed then the probabilities of death involuntary cull and voluntary cull were computed as follows:

$$PD_i = PR_i * D_i.$$

$$PIC_i = PR_i * IC_i$$

$$PVC_i = PR_i - (PD_i + PIC_i).$$

where:

PD_i = Probability of a cow dying in lactation i.

PIC_i = Probability of involuntary cull in lactation i.

PVC_i = Probability of voluntary cull in lactation (or probability of a cow not being disposed due to death or by involuntary culling in a particular lactation).

PR, IC, D are as defined above.

Table 4.7: Calculated Probabilities of Involuntary Culling a Cow in a Particular Year Over 14 Lactations

Lactation	1	2	3	4	5	6	7
Probability of cull	.018	.082	.115	.130	.196	.21	.301
Lactation	8	9	10	11	12	13	14
Probability of cull	.335	.392	.356	.445	.45	.493	.519

Table 4.8: Calculated Probabilities of Death in a Particular Year Over 14 Lactations

Lactation	1	2	3	4	5	6	7
Probability of death	.059	.081	.102	.124	.145	.167	.198
Lactation	8	9	10	11	12	13	14
Probability of death	.211	.232	.251	.275	.296	.318	.339

Table 4.9: Calculated Probability of a Cow Being in a Particular Lactation (Not having been earlier involuntarily culled or died)

Lactation	1	2	3	4	5	6	7
Probability	1.0	.923	.772	.604	.451	.298	.185
Lactation	8	9	10	11	12	13	14
Probability	.088	.04	.015	.006	.001	.0003	.00005

From Table 4.9, it is clear that the probability of a cow living to the 14th lactation, the maximum allowed for our model is very slim. The adjustment explained above gave rise to results in Table 4.10.

Table 4.10: Calculated Transitional Probabilities of Involuntary Cull and Death

Lactation	Probability of Involuntary Cull	Probability of Death
1	.018	.059
2	.076	.075
3	.089	.079
4	.78	.075
5	.088	.065
6	.063	.05
7	.06	.037
8	.029	.019
9	.016	.009
10	.005	.004
11	.003	.002
12	.0004	.0003
13	.00001	.00001
14	.0	.0

Optimal Culling in Current Lactation:

If the outcome demands culling, then the decision becomes one of at what stage in the current lactation to cull. The decision criterion is that you replace the sick cow as soon as the expected income in current lactation falls below the weighted standardized income of a potential replacement heifer. The model does not attempt to establish this point. However, an assumption was made that voluntary and involuntary culling takes place in the tenth month of a lactation under a normal 305 day lactation period based on the usually recommend 12 month calving interval.

Decision on When to Cull:

The decision to cull an animal is made on a lactation by lactation basis. However, as established earlier, one may keep a cow in the herd at a generally low level of production due to higher expected returns in subsequent lactations. This signifies the importance of establishing a tentative optimal herd-life period for the treated cow. Should the production levels be expected to fall throughout the subsequent lactations, then the cow should be culled as soon as the expected standardized income in current lactation of the treated cow falls below the average standardized expected income from a potential replacement heifer. The computation of the relevant value for comparison is done on a lactation by lactation basis as if each lactation occurred in the current period. For each lactation, the net returns, including the opportunity cost of the cow, are traced on a month by month basis from the dry period of previous lactation to the tenth month of the next lactation. The returns are then discounted, accumulated and standardized. In the tenth month, the returns are all weighted for the probability of death and voluntary cull. The computed value (Equation 6) is compared with the weighted standardized value for the potential replacement heifer. If the computed value falls below that of the replacement heifer the cow is to be culled in that lactation.

Decision on Which Treatment to Use:

If the analysis shows that it is more economical to treat based on expected returns, then it is necessary to go on to the next step of determining which treatment among the possible alternatives most economical based on the expected monetary value criterion. In the next chapter, a practical example will be done using cystic ovaries. The evaluation of the optimal strategy to use is based on the decision tree framework. The outcome ($) on the chance nodes are a function of the expected values at the optimal period post treatment and the expected value at the optimal herd-life for the replacement heifer. The analysis has however to ensure that all assessments are made on an equal time framework and using the same units (e.g. present values or annuity values). Where the flows are computed for a particular period, then additional period has to be balanced off by assuming an immediate replacement is in place.

The logic of the analysis is then as follows: A sick animal is treated and if it recovers and the expected flows of income are better than for a replacement, the V_{ij} value is computed. This value gives the monetary outcome for the first node of the respective treatment option. Further analysis is done for a situation where the animal has to be treated a second time. The resulting V_{ij} becomes the monetary outcome on the second node of the respective treatment option. The situation where the animal doesn't recover represents a situation where the animal gets culled and becomes replaced with a potential replacement heifer. The Vij's are used along with corresponding recovery rates to compute the expected monetary values associated with each respective treatment using a modified decision tree presented in Figure 4.4.

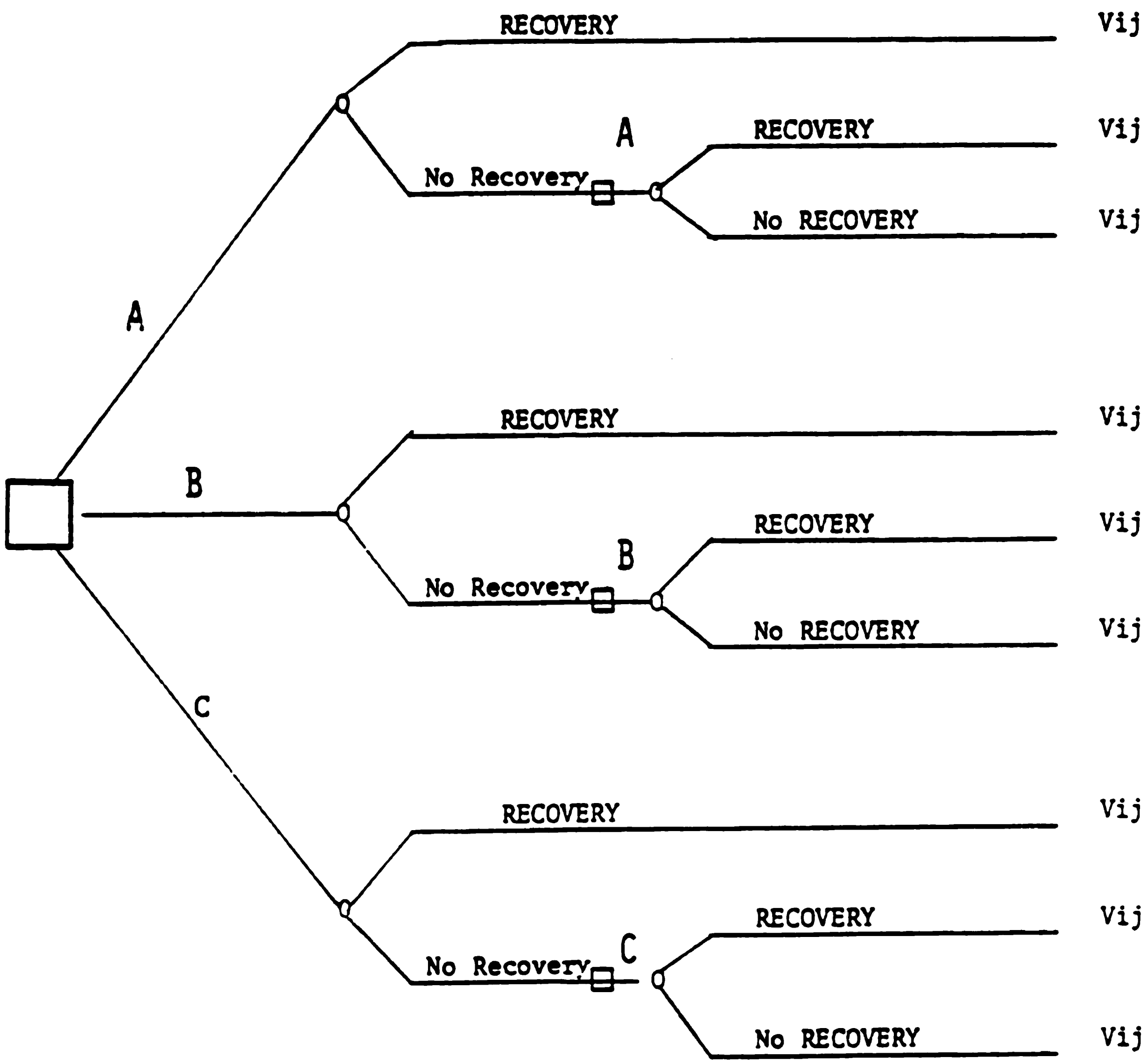
4.5 Model Evaluation:

Model Validation: Validation addresses the adequacy of the model in relation to its purpose. However, before the validity process, one has to check the mathematical and logical correctness of the model. This is often referred to as verification. This was achieved by building the model into modules or subroutines and testing the mathematical and logical correctness of each. Through this verification process the model was found to be logically consistent and hence doing what it was intended to do.

Validation of the model was based on the positivism standpoint; that is, accepting the validity of a model if it is capable of accurate prediction. The verification procedure also allows one to argue that the model was valid since an attempt was made to base the model on relationships and assumptions that can be independently verified (Dent and Blackie, 1979). TELFARM data were used to affirm the positivism criteria. The results of the model were found to be consistent with observed experiences in the Michigan dairy industry.

4.6 Conclusions:

Diseases that reduce production efficiency are of greater concern in animal health programs today than ever before. Our ability to identify the benefit and costs of alternative management programs will go a long way in helping practitioners and farmers make appropriate economic decisions in animal health programs. Decision analysis is one model and may be enhanced with the use of other models like simulation as presented in this study. Our ability to make practical economic decisions in animal health programs will depend on 1) the state of knowledge with respect to animal diseases and the biological/environmental relationships; 2) the ability to translate these relationships into economic terms and 3) the ability to accurately articulate farmer/practitioner attitudes and preferences. The study did not incorporate taxation in the model. The focus of the model was to capture variables to be considered in making the model functional but not to arrive at the cost of disease or management strategy for real farm situations or use in developing policy. It is assumed that individuals who may wish to use the model may want to incorporate the inflation and taxation variables to suit their management situation. Inflation on cost and return values was also assumed to be zero over the modelling period (14 lactations).



V_{ij} = Outcome V for treatment i and State of Nature j.

A, B and C = Management strategies (actions).

Figure 4.4: Modified Decision Tree Framework for the Simulation

CHAPTER V

A CASE ANALYSIS USING CYSTIC FOLLICLES

5.1 Introduction

In order to test the practical usefulness of the model developed in chapter IV, an analysis, using cystic follicles was used. Cystic follicles is a good representative of most diseases which reduce both production and reproduction efficiency. It is representative because its' effects are both direct and indirect and the direct costs do not appear to be detrimental to the dairy industry. In this chapter an epidemiological description of cystic follicles is presented followed by an analysis of its economic impact and an evaluation of the management strategies.

5.2 Bovine Cystic Ovarian Disease

Cystic ovaries is a condition that occurs in cattle especially dairy cattle, and also occasionally in swine. It is characterized by cystic ovarian degeneration leading to failure to ovulate and formation of large cystic follicles, luteal cysts and possibly cystic corpus luteum. An ovarian cyst is defined as a palpable fluid filled ovarian structure with a diameter of 25 mm or greater (Erb and White, 1982).

A follicular cyst is an ovulatory cyst, single or multiple on one or both ovaries with clinical signs that may include nymphomania or anestrus (Bierschwal, et al., 1975). Luteal cysts are smaller in size than follicular cysts, measuring 25-40 mm in diameter. They are in walled and usually only one or two are present at a time with clinical signs of anestrus being predominant. Cystic corpus lutea form from ovulated follicles that do not become solid but retain a fluid-like cavity (vacuole) of varying size in the center. Functionally, the estrus cycle is not affected and are not considered pathologic (Keslev and Garverich, 1982).

Cystic ovarian disease is also characterized by high levels of estrogens in the blood plasma. Progesterone level is frequently low especially with follicular cysts and luteinizing hormone (LH) normal to slightly elevated. The cause of the disease is believed to be the aberration of pituitary gonadotropic hormone release. This hormone is necessary for ovulation. Clinical examinations indicate that the uterus is frequently large, flabby and atonic with the cervix relaxed and open. The heat periods are prolonged with short irregular intervals between them. The animal will exhibit masculine behavior characterized by pawing, bellowing and mounting of other animals while refusing to be mounted itself.

The disease often occurs in the first eight weeks after parturition during the peak of lactation representing the highest peak of occurrence of the disease. However, a second peak of disease outbreak occurs in the third month of a lactation or even latter (Figure 5.1). Diagnosis for the disease is normally done at 20-40 days post-partum prior to breeding to determine any possibility of infection, follicular or corpus luteum malfunctioning. Morrow (1982) reported that cystic follicles are more common between 15 and 45 days after parturition. The disease is also more prevalent in high milking older cows than in heifers. Among the heifers the incidence is higher among those kept many months without breeding or conceiving. Kirk, et al. (1982), have reported that there is a heritable disposition. Their study showed an incidence of cystic ovaries of 44 percent for the offspring of cows that were cystic.

A study on cystic follicles using 2847 lactations from 21 dairy herds in Michigan has reported a lactational incidence rate of 12.8 per cent. With respect to age, a distribution of cystic follicles for 7 different age groups is presented in

Figure 5.2. The results agree with earlier findings showing the prevalence of the disease to be in older cows.

The same study reported a lactational incidence rate by season of calving as; 1) 11.1% for Winter (Dec-Feb) 2) 12.9% for spring (Mar-May), 3) 14.6% for summer (June-Aug) and 4) 13.4% for Fall (Sept-Nov). In relation to production, cystic cows are reported to produce 571 kg more per day adjusted lactation period 305 mature equivalent milk than non-cystic cows. The study thus agrees with earlier findings that cystic follicles are associated with an increased milk production in the lactation in which they occur (Erb, et al. 1980). Figure 5.3 presents the composite lactation curve for lactations with cystic follicles along with a composite lactation curve for lactations which were non-cystic (Bartlett, et al., 1986). From the data used to construct the Figure 5.3, indices were computed to predict monthly production levels for cystic cows (Table 5.1). These indices are used as factors for predicting milk yield for a cow with cystic ovaries compared to a cow that was not cystic.

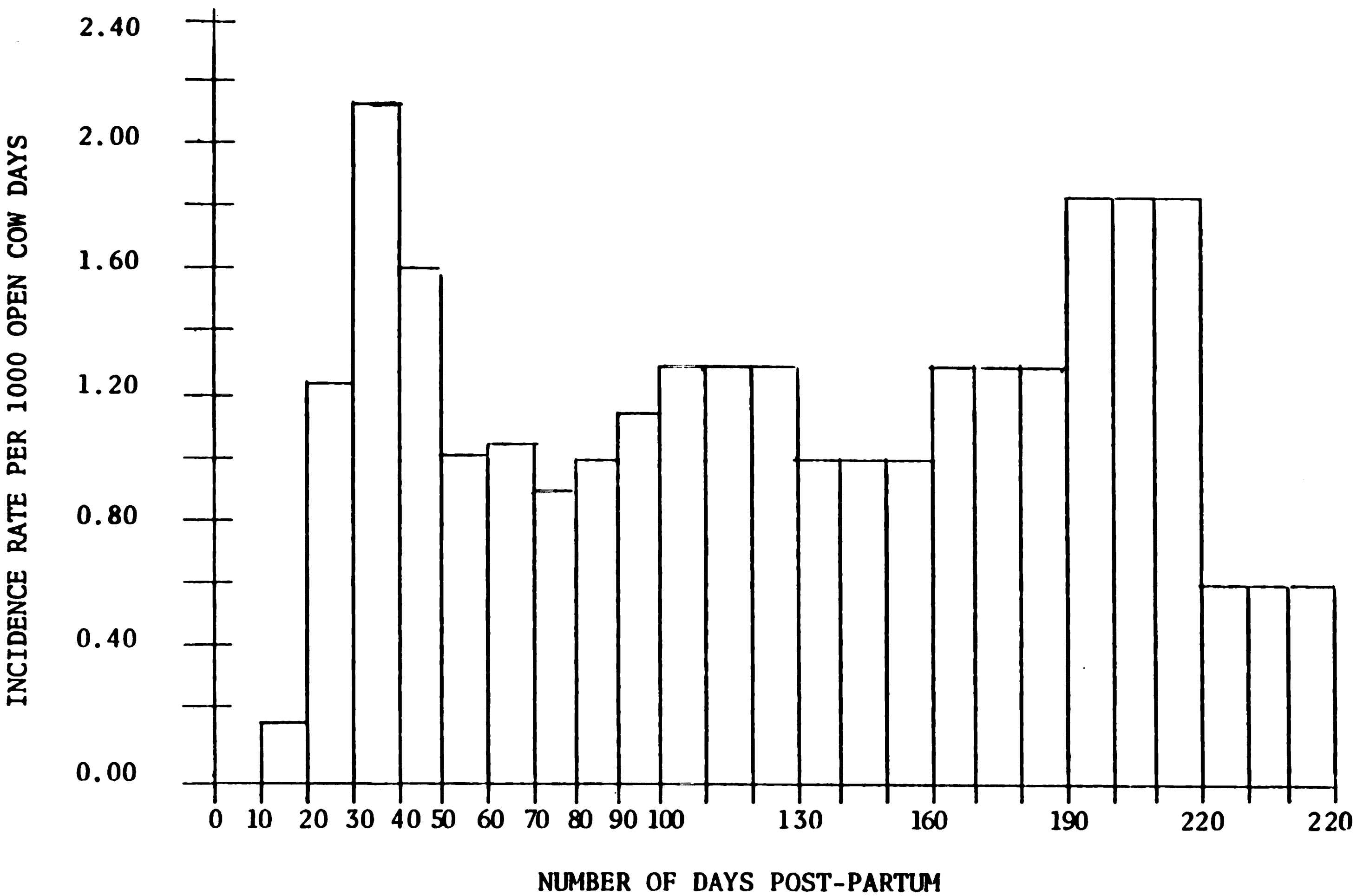


Figure 5.1: Occurrence of Cystic Follicles

Source: FAHRMX data.

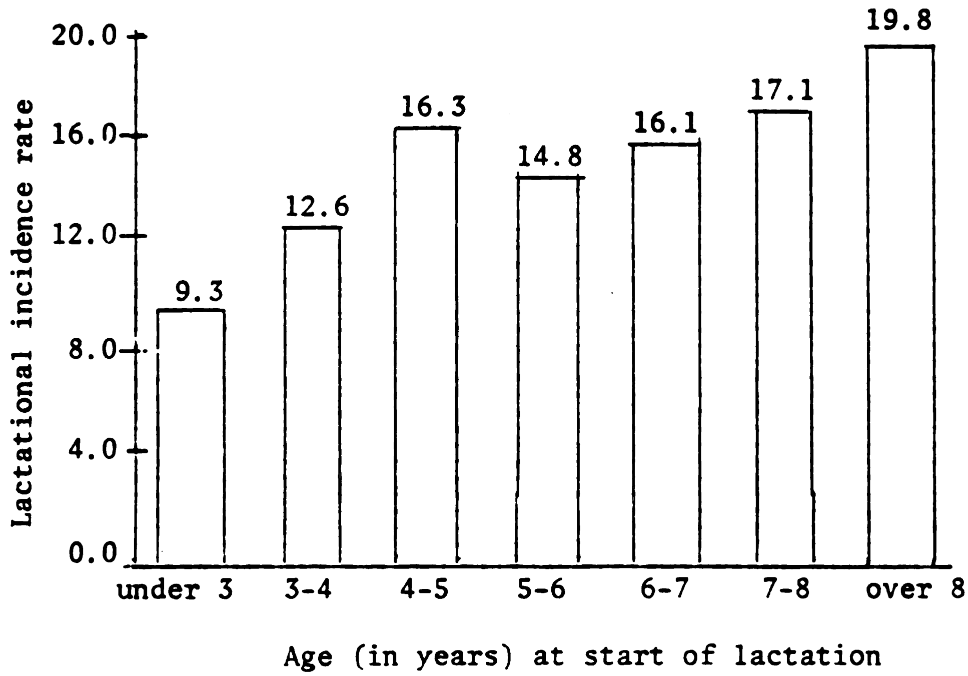


Figure 5.2: The Age-Specific Lactational Incidence Rates of Cystic Follicular Disease

Source: Bartlett, et al., 1986, "Cystic Follicular Disease in Michigan Holstein-Friesian Cattle: Incidence, Descriptive Epidemiology and Economic Impact." Preventive Veterinary Medicine, 4(1986):15-33.

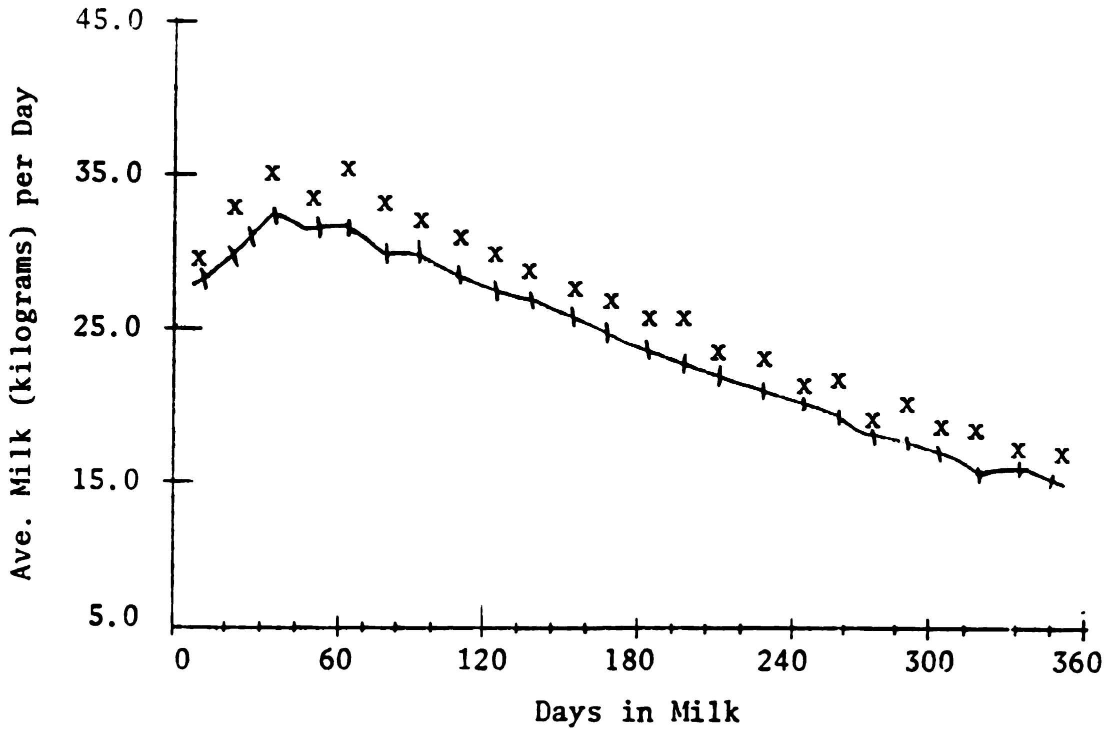


Figure 5.3: Composite Lactation Curve (Actual Milk Production) for Lactations with Cystic Follicles and Non-Cystic Lactations

Where:

++++	Non-cystic lactation
xxx	Cystic lactation

Source: Bartlett et al., 1986. "Cystic Follicular Disease in Michigan Holstein-Friesian Cattle: Incidence, Descriptive Epidemiology and Economic Impact," Preventive Veterinary Medicine, 4(1986):15-33.

Table 5.1: Production Indices for Milk Production Changes for Cystic Cows Over Normal Cows on a Monthly Basis

Month	1	2	3	4	5	6	7
Milk Production Factor	1.01	1.02	1.03	1.04	1.05	1.06	1.07
Month	8	9	10	11	12	13	14
Milk Production Factor	1.08	1.09	1.01	1.02	1.01	1.01	1.01

Source: FAHRMX data.

Although cystic lactations are associated with higher milk production levels, there are associated costs that may outweigh the increased production. As already stated, cystic follicles result in extended calving intervals resulting in delayed milk and calf returns over the subsequent lactations. The delayed flows represent a cost because of the "time value of money". Estimates of the cost of extended calving intervals range from a high of $5.50 (AX, 1984) per day to a low of $.04 (Holmann, et al., 1983). An average of several studies of $2.50 per day has been used by Bartlett, et al. (1986). Since the debate on the cost of extended days open has not been resolved, the analysis will attempt to infer from the model results an estimate of the cost of extended calving interval. Another concern associated with cystic follicles is the category of direct costs associated with treatment and the selection of optimal treatment strategies.

Follicular cysts are most often treated with one of two forms of hormone therapy: 1) Luteotrophic agents such as human chronic gonadotropin (HCG) and gonadotropin releasing hormone (GNRH) are used to cause the luteinization of ovarian follicles, 2) Luteolytic substance, such as prostaglandin (PGF_{2a}), are applied to induce regression of luteal tissue and occurrence of a normal estrus in the case of luteal cysts. Nakao, et al. (1983) in studying cows with cystic ovaries have reported an incidence rate of 65 per cent for cystic follicles, 19 percent for luteal cysts and 16 percent for corpora lutea. Results from Michigan Holstein-Friesian cattle between 1981-1985 showed that 187 treatment of GNRH were administered to cows with cystic follicles at a mean dose of 100 mcg (2cc) and mean cost of $8.00 per dose and 196 treatments of HCG were administered at a mean does of 10,000 (U(10cc) and mean cost of $13.10 per dose (Bartlett, et al., 1986). Prostaglandin, manual rupture, and other treatments were also used. Treatment with HCG and GNRH has shown differences in the response rates to treatment and in the intervals to the onset of estrus and in conception rates

(Kesler and Garverich, 1982, Ax et al., 1984). For best results, it has been recommended that these two most commonly used treatments be used alternately (Whitemore, 1984).

The management of ovarian cysts requires a framework for determining the most economical strategy, especially with respect to choosing the most economical treatment to use. Such a framework will require the incorporation of factors like treatment response rates, days to onset of estrus, costs of treatment and examination, and the value of treatment success or failure. White and Erb (1980, 1982) have used the decision-tree technique to demonstrate that it is more economical to treat ovarian cysts than to refrain from treatment and also more economical to establish the optimum post-partum interval for screening dairy cows for ovarian cysts. However, in their analysis, only one treatment (GNRH) was considered and contrasted with the option of withholding treatment, hence relying on spontaneous recovery. The value of the animal subsequent to treatment was not incorporated in the analysis, although they noted its significance. Madison, et al. (1984), however, in discussing the use of decision analysis in animal health practice, make the assumption that an unsuccessful intervention (e.g. treatment) has an outcome value of zero. Such an assumption may result in gross errors in analysis for diseases like ovarian cysts, where an unsuccessful intervention (animal retaining the ovarian cysts) may only mean a temporary delay in future earnings by way of delayed conception, or at most, failure to conceive but still retaining the direct value of the animal for meat. The analysis of the economic benefits and costs of alternative treatment strategies incorporating the value of the animal post-treatment is an important management function in treating cystic follicles beyond the decision to treat or not to treat. One objective of the analysis is to use the model to make an economic evaluation of the treatment strategies of cystic follicles using GNRH and HCG. Specifically, three treatment strategies are contrasted. They are (1) successive treatments with GNRH (GNRH/GHRH); (2) successive treatment with HCG (HCG/HCG); and (3) successive withholding of treatment, NT (NT/NT).

Part of the data for this analysis were obtained from the Food Animal Health Resource Management System (FAHRMX) at Michigan State University and the rest were obtained from the literature. The mean cost per cow for a veterinary reproductive examination from a survey in Michigan was $3.00. Treatment costs were $8.00 for GNRH and $13.00 for HCG per treatment per animal. The value of cows purchased for dairy purposes was $1500 and $500 for cows sold for slaughter (Bartlett, et al., 1986). These values were used to represent the value of the animal on complete recovery, and failure to recover, respectively.

Data from FAHRMX were not used for deriving probabilities of response due to the small sample size of animals and the fact that treatment success or failure could only be guessed for most of the recorded cases. Thus, parameters were derived from secondary sources. The probabilities for the initial response to treatment and days to resumption of estrus were from Whitemore (1979), and from Kesler and Gaverich (1982). Days to estrus were estimated as 30 days. There were no data available for response to successive treatments with HCG or for alternating treatments between HCG and GNRH. In those circumstances, the same probability of response as on initial treatment was used. This, however, ignores the fact that response rates change with repeated treatments as observed by Whitmore, et al. (1979). The analysis allowed for an animal to be treated a second time if there was no recovery on first treatment. This was based on the knowledge that at least 90 percent of the animals treated for follicular cysts recover by the second treatment (Whitemore, 1984). Therefore, if a cow fails to recover after two successive treatments, it is considered to be sterile and sold for meat in this analysis.

The decision criterion for selecting the optimal intervention was the expected monetary value (EMV). This was computed by summation of the net monetary returns for each state and action choice multiplied by their respective probabilities.

$$EMV_i = \sum_{i=1}^{N} P_{ij} \cdot V_{ij}$$

where:

P_{ij} = The probability of occurrence of state of nature j under management strategy i, i = 1,2---N.

V_{ij} = Value of the outcome for state of nature j under management strategy i. V_{ij} is a function of the expected monthly income for strategy i under the state of nature j. The computation involves the period in months over which the returns are expected. These returns are a function of the benefit flows (milk and calf values) and the costs (feeds, costs of treatment, general health costs and opportunity costs). (See Section 5.4.)

5.3 Simulation Results

The base run was represented by a potential replacement heifer in her first lactation with an expected production level of 16000 lbs per 10 month lactation. The heifer was to have her first calving in January and a cow index of 90 and a sire predicted difference of 70 was used for evaluating calf values. The model was run over a 14 year period on a monthly basis. The following milk income, calf values, feed and health costs, and net income were generated by the model.

Table 5.2 Monthly Costs and Returns for a Potential Replacement Heifer in Lactation One

Month	Milk Value ($)	Calf Value ($)	Feed Cost ($)	Health Costs ($)	Cow Opportunity Cost ($)	Net Income ($)
					-1500	-1500
1	199.20	97.05	115.37	21.20	0.0	159.68
2	199.20	0.0	115.37	11.20	0.0	72.63
3	187.9	0.0	108.79	7.87	0.0	71.24
4	178.6	0.0	103.40	5.20	0.0	69.0
5	164.0	0.0	95.14	5.20	0.0	63.66
6	149.8	0.0	87.11	4.53	0.0	58.16
7	145.3	0.0	84.62	4.06	0.0	56.62
8	137.0	0.0	80.03	3.70	0.0	53.27
9	124.2	0.0	72.96	3.42	0.0	47.82
10	114.9	0.0	68.33	3.20	0.0	43.37
11	0.0	0.0	32.74	3.20	0.0	-35.76
12	0.0	0.0	32.74	2.87	0.0	-35.61

Source: Base run results.

The respective flows of income and costs are a function of time within the lactation. As has been argued, feed costs and health costs are closely associated with the level of milk production which is also associated with time in the lactation. The net returns are simultaneously discounted and standardized using a 12 percent discount rate to give the flows represented in Table 5.3. The 12

Table 5.3 Net Discounted and Annualized Returns for the Potential Replacement Heifer in Lactation One

Month	Net Income $	Discounted Income $	Standardized Income $
0	-15000	-1500	-1500
1	159.677	158.10	-1355.32
2	72.3	71.20	-644.90
3	71.24	69.15	-408.56
4	69.0	66.31	-290.95
5	63.66	60.57	-221.43
6	58.16	54.79	-175.98
7	56.62	52.81	-143.74
8	53.27	49.19	-119.960
9	47.82	43.72	-102.05
10	43.37	39.27	-88.15
11	-35.76	-32.05	-83.62
12	-35.61	-31.60	-79.84

Source: Base run results..

percent rate was selected based on the 5 percent real interest rate and 6% inflation plus 1 percent allowance for changes available at farm level during the early to mid 1980 period.

As a result of the high opportunity cost of keeping the potential replacement heifer in the herd as opposed to selling it for dairy purposes, the flows, standardized on a monthly basis, stay negative over the entire first and second lactation until later in the third lactation.

The discounted returns were weighted by the probability of voluntary cull and death over the entire 14 lactations and standardized on a lactation by lactation basis. The results show (Table 5.4) an increase in weighted standardized returns from a negative value in the first lactation reaching a maximum in the 4th lactation and falling down close zero to through lactations 12, 13 and 14. These results give us a tentative optimal period to keep the potential replacement under the assumptions made earlier. The maximum value of $16.22 can be interpreted to mean that over the 4 lactations, one would expect to earn a net return of $16.22 per month.

Table 5.4 Weighted Standardized Returns for the Replacement Heifer Returns Over Her Life Span

Year	Monthly Returns $	Year	Monthly Returns $
1	-44.33	8	3.30
2	4.03	9	1.54
3	14.99	10	.59
4	16.22	11	.21
5	14.11	12	.04
6	10.14	13	.01
7	6.49	14	.003

Source: Base run results..

Simulation Results for a Hypothetical Cystic Cow

The cystic cow was represented by one in her third lactation with a yield of 14,000 lbs in a normal 10 month lactation. The replacement heifer has an advantage over the cystic cow due to improvement in genetic potential of about 1% per year. For the simulation, however, the flows of benefits and costs were assumed to start in the third month (an average period in which treatments for cystic ovaries are made). Secondly, milk production was extended by one month if cow was assumed to recover on first treatment and by two months if cow was assumed to recover after two treatments. Thirdly, milk production levels were adjusted by the cystic factor to allow for increased levels of production associated with cystic ovaries in the particular lactation.

Table 5.5: Monthly Costs and Returns for a Cystic Cow With a Successful Treatment of HCG

Month of Lactation	Milk Value $	Calf Value $	Feed Costs $	Health Costs $	Opportunity Costs $	Net Income $
					-500	-500
3	162.9	0.0	82.31	22.67	0.0	57.92
4	156.6	0.0	79.92	5.00	0.0	71.68
5	147.6	0.0	76.51	4.00	0.0	67.09
6	135.6	0.0	72.02	3.33	0.0	60.24
7	127.5	0.0	69.0	2.86	0.0	55.65
8	115.2	0.0	64.43	2.50	0.0	48.27
9	108.0	0.0	61.79	2.22	0.0	43.99
10	94.5	0.0	56.83	2.00	0.0	35.67
11	81.0	0.0	55.18	1.82	0.0	24.0
12	0.0	0.0	37.22	1.62	0.0	-38.89
13	0.0	0.0	37.22	1.54	0.0	-38.65

Source: Base run results..

Table 5.6: Net, Discounted and Standardized Returns for a Cystic Cow with a Successful Treatment of HCG

Month	Net Income	Discounted Income	Standardized Income
	-500	-500	-500
3	57.92	57.35	-447.08
4	71.68	70.27	-188.99
5	67.09	65.11	-104.48
6	60.24	57.89	-63.91
7	55.65	52.95	-40.47
8	48.27	45.47	-26.05
9	43.99	41.03	-16.34
10	35.67	32.94	-10.06
11	24.0	21.95	-6.43
12	-38.89	-35.21	-9.53
13	-38.76	-34.74	-12.06

Source: Base run results..

As shown in Table 5.5 no calf value appears in the first lactation since the simulation starts in the 3rd month. Also, the health costs are relatively high in the third month because treatment with HCG is assumed.

The $500 at the beginning of the simulation period represents the opportunity cost of keeping the cow and deciding to treat it as opposed to having sold it for meat. Table 5.6 shows the net, discounted and standardized returns for the cystic cow over the lactation. The results in Tables 5.5 and 5.6 are almost duplicated for a situation where the cow is treated twice before recovery except that (1) health costs increase in the first and second month of the simulation by the cost of treatment; (2) the lactation period is extended by two months hence having implications on milk returns, feed costs and health costs (Table 5.7 and 5.8).

Table 5.7: Monthly Costs and Returns for a Cystic Cow After Two Treatments of HCG

Month of Lactation	Milk Value $	Calf Value $	Feed Costs $	Health Costs $	Opportunity Cost $	Net Income $
					-500	500
3	162.9	0.0	82.31	22.67	0.0	57.92
4	156.6	0.0	79.92	21.00	0.0	55.68
5	147.6	0.0	76.51	4.00	0.0	67.09
6	135.6	0.0	72.02	3.33	0.0	60.24
7	127.5	0.0	69.0	2.86	0.0	55.65
8	115.2	0.0	64.43	2.50	0.0	48.27
9	108.0	0.0	61.79	2.23	0.0	43.99
10	94.5	0.0	56.83	2.00	0.0	35.67
11	81.0	0.0	55.18	1.82	0.0	24.00
12	67.5	0.0	55.18	1.67	0.0	10.65
13	0.0	0.0	37.22	1.54	0.0	-38.76
14	0.0	0.0	37.22	1.43	0.0	-38.65

Source: Base run results..

Table 5.8: Net, Discounted and Standardized Returns for a Cystic Cow with Two Successive Treatments of HCG

Month	Net Income	Discounted Income	Standardized Income
3	57.92	57.35	-447.08
4	71.68	70.27	-196.95
5	67.09	65.11	-109.81
6	60.24	57.89	-67.93
7	55.65	52.95	-43.70
8	48.77	45.47	-28.75
9	43.99	41.03	-18.67
10	35.67	32.94	-12.11
11	24.0	21.95	-8.26
12	10.65	9.64	-6.45
13	-38.89	-35.21	-9.24
14	-38.76	-34.74	-11.56

Source: Base run results..

Table 5.9 Weighted Standardized Returns Over the Lifespan for the Cystic Cow Treated with HCG

Lactation	Weighted Standardized Income $
1	--
2	--
3	30.23
4	28.53
5	22.47
6	15.15
7	9.27
8	4.56
9	2.05
10	.76
11	.26
12	.05
13	.01
14	.003

Source: Base run results.

The weighted standardized returns for the cystic cow are shown in Table 5.9. Economically, the cow is at her best in the third lactation with expected monthly returns of $30.23 per month. Relative to a replacement heifer, however, it is more economical up to the 5th lactation, generating $22.47 per month.

Interesting enough, this particular cow would be doing better than the potential replacement over her lifespan, thus implying that if her production can be maintained and she does not die, it would be best to treat her and keep her instead of culling in favor of a replacement.

However, there is still the crucial decision of when to cull the cow because this decision is basically made based on comparing the expected weighted returns of the next lactation with expected weighted returns from a replacement. Thus the weighted individual lactation returns were computed for comparison purposes with the potential replacements' weighted standardized returns (Table 5.10).

Table 5.10: Weighted Individual Lactation Standardized Returns for the Cystic Cow Treated with HCG

Lactation	WILSTDINC $
3	—
4	26.14
5	14.99
6	8.83
7	4.13
8	1.52
9	0.38
10	0.09
11	0.06
12	0.02
13	0.003
14	0.0

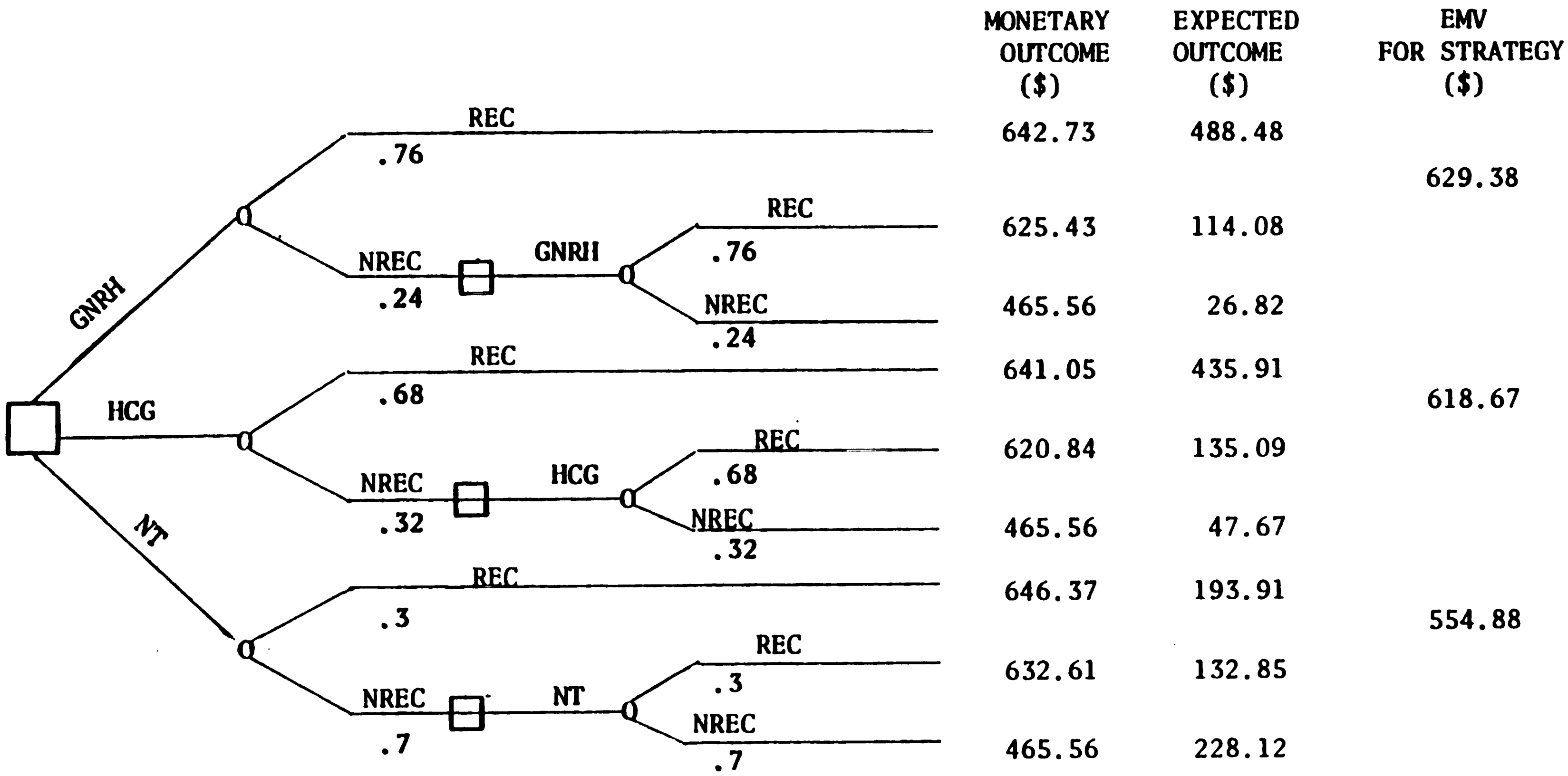
Source: Base run results.

5.4 Choice of Management Strategy:

The selection of the most economical management strategy was based on the expected monetary value (EMV) criterion. Three strategies were analyzed, namely:

1. Two successive treatments with GNRH
2. Two successive treatments with HCG
3. Two successive decisions of not treating the animal

The results of the model show that the cystic cow, whether treated or not, would be generating economic returns that are much higher than those of the replacement heifer up to the fifth lactation. If successfully treated with GNRH, a monthly return of $22.55 would be generated over the 33 months (from period of treatment to end of 5th lactation). If a second treatment is needed, then the resulting monthly returns are $21.79 over the 34 months (including the month of extended calving interval). For HCG the corresponding values are $22.47 and $21.63, respectively and the strategy of no treatment generates $22.68 and $22.04, respectively. The decision to cull the cow on diagnosing cystic ovaries would imply that a replacement would be made resulting in a monthly return of $16.22 per month. The returns are discounted to generated present values and weighted by the probability of occurrence to compute the expected monetary values as presented in Figure 5.4 (Node by node computation are explained below using the GNRH strategy.).



Where: REC = Recovery
NREC = Non Recovery

Figure 5.4: Results of a Modified Decision Tree Framework of the Simulation

Expected Values Under the GNRH Treatment Strategy:

If a cow is treated with GNRH and recovers on the first treatment, then it may be kept on for at least two more lactations based on the fact that the weighted individual lactation returns are higher on a lactation basis than for a replacement heifer over her potential optimal lifespan. At the end of the fifth lactation, the monthly flows are computed to be $22.55 per month over 33 months. This gives a present value of $22.55 times 27.9897 (the present value of a dollar received monthly at a 12% discount over 33 months, that is, an annuity factor). To the product, $631.17, will be added an additional month's expected return from a replacement heifer. This value will be added only for one month because the desire is to have an equal planning period for each management strategy and in this case the basis is that each strategy allows for a second treatment in case of failure on the first one. This income would be realised in the 34th month. The $16.22 has a present value of $11.56 (16.22 x .713, the discount factor). This gives a total present value of 642.73 for node 1. The expected present value is a function of the present and probability the particular state of nature occurring (.76). Thus the expected present value on the first node is 642.73 x .76 = $488.48.

The second node represents a situation where the cystic cow recovers only after the second treatment. On recovery, the cow would have a potential of going through the 5th lactation with monthly returns above those of the potential replacement heifer at the optimal level. The monthly returns are computed at the level of $21.79 per month. This value, multiplied by the annuity factor (28.7027) gives a present value of 625.43. Given the probability of occurrence for this state of nature, the expected present value comes to be $114.08 (625.43 x .24 x .76).

The third node represents a situation where the cow does not recover and is replaced soon after the second treatment by the potential replacement heifer.

Thus over the reminder of the period, the returns are estimated by those of the potential replacement, $16.22. Over the 34 month period, this gives a present value of $465.56. This value, weighted by the probability of occurrence for the state of nature gives an expected value of 26.82 (465.56 x .24 x .24). Thus the total expected value of treating with GNR is $629.38 (488.48 + 114.08 + 26.82).

Similar computations are made for the treatment of HCG and NT. Expected values for the three management strategies are computed by incorporating the probabilities of the occurrence of the respective states of nature.

The results (Figure 5.4) show that the management strategy of using GNRH results in the highest expected value $629.38 compared to HCG ($618.67) and NT ($554.88). The difference between the GNRH strategy and HCG strategy is only $10.71. However, the difference between the no treatment strategy and the two treatment strategies is over $60.00 in each case. These results add to the argument that treatment is more economical than no treatment for cystic ovaries. However, the difference in expected values between GNRH and HCG reinforce the difficulty in selecting one strategy over the other based on the $10.71 monetary difference between the two.

5.5 Cost of Days Open:

Estimation of the cost per day of extended estrus or day open is one of the areas of contention in the evaluation of the economic impact of animal diseases that cause extended calving intervals. The results of the study may put some light on the analysis since the model analyses the entire life span of the animal in question over different days of extended calving interval. One approach used here is to compare the difference in expected monthly returns over a situation where the cow had an extension of the calving interval by one month with the situation where calving interval was less than one month due to spontaneous recovery from diagnosed cystic ovaries. In this case the comparison is made between node 1 and node 2 for the no treatment (NT) strategy. For the NT strategy, the difference between node 1 and 2 is $13.76 (646.37 - 632.61) based on present monetary values (Figure 5.4). This difference occurs just because of an extended calving interval of 1 month. This represents a daily average of $.45 (13.76/30). This becomes, therefore, an approximation of costs per day open.

5.6 Sensitivity Analysis

The analytical model presented in this study uses a broad range of variables and variable parameters based on certain assumptions. These variables relate to level of milk production and lactation curves, feeds and feed costs, lactation number and month, treatments and their costs, animal response to treatment, cow and calf values, general health costs and their distribution over lactations, probabilities of death, involuntary and voluntary culling and milk prices. Theoretically, sensitivity analysis should test the sensitivity of the model to changes in the above variables. However, it is clear that some of the variables would have a relative impact on the results of the model especially with regard to optimal lifespan and relative profitability of management strategies. The author felt that the following variables were more critical and sensitivity analysis was conducted on them using the model. These variables were: (1) level of milk production; (2) lactation number; (3) treatment cost; and (4) animal value and salvage value.

A. Level of Milk Production:

As already stated, milk returns are the most important when tracing the flow of returns from dairy cattle over time. As such these would have significant impact on choice of management strategy and optimal animal lifespan. Table 5.11

represents weighted standardized returns of potential replacement heifers at different levels of milk production in first lactation. In general high production in first lactation results in higher standardized returns over the first several lactations, in general terms. As the cow lives beyond lactation 8 or so, the expected standardized returns in general will diminish to such an extent that the distinction between initially high producers and low producers become less pronounced. All the heifers would reach their highest production level, based on weighted standardized returns, in the fourth or fifth lactation. However, the major impact of higher producers would be to lower the timing when a cystic cow would be replaced. With low producing heifers, the cystic cow in the base run would be kept for one lactation or longer.

Table 5.11: Weighted Standardized Returns for Potential Replacements at Different Levels of Milk Production in the First Lactations

	12,000	14,000	16,000	18,000
1.	-61.69	-52.04	-44.33	-38.64
2.	-10.05	-1.94	4.03	8.62
3.	3.96	10.38	14.98	18.71
4.	7.95	12.76	16.22	19.16
5.	8.11	11.59	14.11	16.34
6.	6.26	8.51	10.14	11.62
7.	4.17	5.51	6.49	7.39
8.	2.18	2.83	3.30	3.74
9.	1.03	1.32	1.54	1.73
10.	.40	.51	.59	.66
11.	.14	.18	.21	.24
12.	.03	.04	.04	.05
13.	.01	.01	.01	.01
14.	.001	.002	.003	.003

Source: Sensitivity analysis run.

Table 5.12: Weighted Standardized Returns for a Cystic Cow at Different Levels of Milk Production

Production (1st lactation)	14,000	16,000	18,000	20,000
Lactation				
3	30.23	43.94	45.89	52.90
4	28.53	36.65	37.75	42.88
5	22.47	27.92	28.63	31.88
6	15.15	18.54	18.87	21.05
7	9.27	11.26	11.51	12.75
8	4.56	5.52	5.64	6.24
9	2.06	2.49	2.55	2.82
10	.76	.94	.96	1.06
11	.26	.32	.34	.37
12	.05	.06	.07	.07
13	.01	.02	.02	.02
14	.003	.004	.004	.005

Source: Sensitivity analysis run.

Table 5.13: Weighted Standardized Returns for a Cystic Cow at Different Beginning Lactations

Beginning Lactation	2	3	4	5	6
2	41.98	--	--	--	--
3	36.83	30.23	--	--	--
4	29.49	28.53	29.15	--	--
5	22.34	22.47	23.91	21.01	--
6	14.81	15.15	16.07	15.43	13.27
7	9.0	9.27	9.79	9.51	9.09
8	4.41	4.56	4.81	4.71	4.59
9	2.0	2.06	2.17	2.13	2.08
10	.76	.76	.81	.79	.78
11	.26	.26	.28	.27	.27
12	.05	.05	.05	.05	.05
13	.01	.01	.02	.01	.01
14	.004	.003	.004	.004	.003

Source: Sensitivity analysis run.

Table 5.12 presents weighted standardized returns for a cystic cow at four levels of milk production in first lactation. High first lactation production levels are reflected in higher returns in the first several lactations and later the differences diminish as the cow gets older. Higher returns also mean that one would prefer to treat and keep the cystic cow longer based on monetary expectations than with low level producers. Thus whereas the base run had the cow reach its maximum optimal level (relative to replacement) in the 5 lactation, higher producers would attain this level in the 6th lactation.

B. Lactation Number:

The lactation number has a definite impact on the model results. First of all as the cow gets older, the production level may increase around the 3rd, 4th or 5th lactation. However, in latter lactations, production level falls and in addition, the cow is more vulnerable to disease and other ailments. Table 5.13 shows the results of the base run cow having cystic ovaries at different lactations. The results show that if the cow is in lower lactations, the economical choice would be to treat and, on the other hand if the same cow is in lactation 5 or above, keeping the cow would not be economical and hence replacing the cow would be a most economical decision.

C. Treatment Cost:

The costs of treatment including examination costs were some of the lowest items influencing the flow of returns over an animal lifespan. This is expected given the cost of drugs that were the focus of the model. Table 5.14 shows the weighted standardized returns over 14 lactations with cost of drugs ranging from $0.0 to $26.0. The $26.0 represents a doubling of the $13.00 cost of HCG and $6.5 represents half the price. Similarly $4.0 represents half the price of GNRH and

$16.00 twice the GNRH price. Clearly treatment cost has insignificant impact and hence where the effectiveness of each treatment is not well known, selection between the treatments may remain to be based on other factors rather than cost especially in Michigan.

D. Animal Value:

The base run assumed a potential replacement to be valued at $1500 and an older cystic cow in 3rd lactation and above at $500. These values were arbitrarily taken from a previous study that used the same values (Ngategize et al., 1986). The impact of changing these values for both the potential replacement heifer and the cow are represented in Table 5.15. As the results show the assumption on the value of the potential replacement has an impact on returns and hence optimal replacement as determined by the model.

Table 5.14: Weighted Standardized Returns for a Cystic Cow With Different Treatment Costs

Treatment Cost ($)	0.0	4.0	6.50	8.00	13.00	16.00	26.00
Lactation							
3	31.39	31.03	30.81	30.68	30.23	29.96	29.07
4	28.94	28.82	28.74	28.69	28.53	28.43	28.12
5	22.68	22.62	22.58	22.55	22.47	22.43	22.27
6	15.25	15.22	15.20	15.19	15.15	15.12	15.04
7	9.32	9.31	9.30	9.29	9.27	9.26	9.22
8	4.59	4.58	4.58	4.57	4.56	4.56	4.54
9	2.06	2.05	2.05	2.05	2.06	2.04	2.04
10	.76	.76	.76	.76	.76	.76	.76
11	.26	.26	.26	.26	.26	.26	.26
12	.05	.05	.05	.05	.05	.05	.05
13	.01	.01	.01	.01	.01	.01	.01
14	.003	.003	.003	.003	.003	.003	.003

Table 5.15: Weighted Standardized Returns at Different Heifer and Cow Value Assumptions

Cow/Beef Value = $500

Lactation	Heifer Value 1750	Heifer Value 1500	Heifer Value 1000
1	-70.73	-44.33	8.46
2	-7.70	4.03	27.49
3	8.27	14.98	28.43
4	12.11	16.22	24.45
5	11.54	14.11	19.27
6	8.66	10.14	13.10
7	5.68	6.49	8.11
8	2.94	3.30	4.03
9	1.38	1.54	1.84
10	.54	.59	.70
11	.19	.21	.25
12	.04	.04	.05
13	.01	.01	.01
14	.003	.003	.003

Heifer Value = $1500

Lactation	Cow Value 250	Cow Value 500	Cow Value 750
3	52.75	30.23	7.71
4	36.54	28.53	20.52
5	26.51	22.47	18.44
6	17.21	15.15	13.09
7	10.31	9.27	8.23
8	5.01	4.56	4.12
9	2.23	2.05	1.87
10	.82	.76	.70
11	.28	.26	.24
12	.06	.05	.05
13	.02	.01	.01
14	.004	.003	.003

5.7 Conclusion:

The results from the model show that the best management strategy for cystic ovaries is treatment with GNRH. However, under the assumptions of the model, all the management strategies result in relatively the same standardized returns over the 14 lactation lifespan. This is expected given that the costs associated with treating cystic ovaries are generally low compared to other variables that affect the flow of returns like milk production and feed costs. The optimal lifespan of 4 or 5 lactations was also not unique as has been reported by other researchers (Hlubik, 1979). On most dairy farms in Michigan it is not common to have cows going beyond 4 to 5 lactations. This is also an added validation of our model assumptions in spite of the fact that some variables for selection and keeping dairy cows on the farm like temperament were not included in the model. Dijkuizen et al. (1985) have already shown that a cow may be breed up to six times with the hope of becoming pregnant before thinking of replacing it, all other factors being equal. Thus for a cystic ovary condition, where 90 percent recover on the second treatment, it is always advisable to treat or even withdraw treatment up to 2 months with the expectation of spontaneous recovery rather than cull based on cystic ovaries alone.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary

The general objective of the study was to develop an analytical model that could be used in evaluating the economic impact of animal diseases that reduce production efficiency and in assessing the benefits and costs of alternative management strategies.

Three years prior to the beginning of the study, the Kellogg Foundation had granted 1/2 million dollars to the FAHRMX team to develop a computerized herd-health program that would be instrumental in addressing animal health problems in dairy farms, especially in Michigan. For a long time, animal diseases have been managed by protocol. A sick animal was treated according to the current knowledge and technology about the disease. Disease impacts that offered great concern were the ones that caused mortality or observable defects. The increasing pressure on farmers arising from increasing competition, increasing production costs and declining farm product prices has given rise to a growing attention to the diseases that cause reduction in production efficiency. The economic impact of such diseases are generally intangible and are spread over the productive life of the animal. Diseases causing such impacts include cystic ovaries, metritis, mastitis and dystocia. Cystic ovarian disease has among others, the impact of prolonging the calving interval. This implies that future expected returns from calves, milk and others are postponed even more. This represents a cost since, as already stated, "a dollar today is worth more than a dollar tomorrow." Secondly, there are the costs associated with the treatment of the disease like drug cost, veterinarian costs and others. It has been shown that a cow suffering from cystic ovaries will produce more milk over the lactation than in a lactation without cystic ovaries. The complexity represented by diseases that reduce reproductive efficiency represents a challenge in attempting to quantify disease impacts and put a monetary value on the respective impacts.

Another problem associated with managing such diseases is selection among alternative management or treatment strategies. There is an increasing range of treatments on the market. Each treatment is differentiated from another to meet a specific objective but sometimes the differentiation is to make it more attractive to buyers. Thus, it becomes a problem for the user (farmer) to select the treatment that is appropriate for his situation. The study attempted to address the broad area of evaluating the economic impact of diseases on production by using cystic ovarian disease as a case study.

From a broad range of statistical/epidemiological and economic models decision analysis was used as the anlytical framework for the model. The limitation of generating model inputs and outputs over time was overcome using simulation analysis. Thus, the resulting model was an integration of decision analysis with simulation that utilizes dynamic programming to generate the monetary outcomes for the decision nodes. The model viewed a cow as a durable asset, with benefits and costs occurring over time (14 year period) with the possibilities of death, involuntary culling or voluntary culling (based on production). In each case, a replacement heifer was available.

The results showed that the potential replacement heifer would reach its highest economic based on weighted standardized returns in the 4th or 5th lactation while the cystic cow would reach the point in the 5th lactation. GNRH was superior to HCG and NT and a $.45 cost per day was estimated for each day of extended estrus.

6.2 Conclusions and Recommendations:

The reduction of production costs by farmers will partly be made by the ability of farmers to determine the benefit-costs of diseases that reduce production efficiency of dairy cows and evaluating the alternative management strategies for those diseases. Because such diseases give rise to costs that tend to be indirect rather than direct, out-of-pocket expenses, or cow mortality, they have long been of less concern to the farmer. Even where a small amount of money spent on treating or controlling the disease would result in increased returns, most people may not see the returns as direct and hence become reluctant to incur the extra costs. This problem can be overcome by developing models and analysis that can give the explicit benefits and costs of such diseases and their management strategies so that farmers have a basis for selection between alternatives and deciding on actions to take.

In addition to meeting the objectives of the study, the developed model represents an improvement on previous use of decision analysis and evaluation of disease cost by having:

1) incorporated the value of the animal in the analysis;
2) the ability to simulate returns over time thus analysing the cow as a durable asset;
3) the capacity to make decisions relating to culling and replacement;
4) the ability to evaluate the cost of days past the optimal dry period; and
5) The ability to incorporate many variables and parameters to generate monetary outcomes and to conduct sensitivity analysis efficiently.

The limitations of the study are related to weak or insufficient data for economic analysis. Without good economic analysis, FAHRMX can not be able to provide farmers with sufficient information for decision making. As a result farmers may be frustrated. Therefore, there is a stronger need to support more research and less need to stress on the extension related goals of FAHRMX until sufficient information generated by tested models are available. There is need for further research in:

1) Improved data and variable coefficients. For example, the probability of occurrence of a disease over the cows lifespan and the impact of such a disease over the lifespan and also to evaluate if there is any significant saving of money on feeds when an animal is off feed during a disease episode.

2) Incorporating the expected utility hypothesis. Farmers goals and objectives are more than monetary. The expected utility hypothesis would result in a more objective decision criteria.

3) Adaption of the model to other diseases. Other diseases have different impacts with regard to magnitude timing and specific effects. The model could easily be adpated to many other diseases.

To the extent that research in these areas is not well developed, programs like FAHRMX may be too ambitious with respect to the extension component.

APPENDIX A

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APPENDIX B

COMPUTER PROGRAM CODE

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*JOBCARD*,JOB ,ACMISC,BAS,LI...*
discose,**,a.
*tn5.
mode,1.
lgo.
*eor
      PROGRAM DECANA(input,output,tape5=input,tape6=output)

C INTRODUCTION.
C THE PROGRAM,DECANA,WAS WRITTEN BY PETER NGATEGIZE IN PARTIAL FULFIL-
C MENT OF THE REQUIREMENTS FOR A PH.D IN AGRICULTURAL ECONOMICS.
C
C PROGRAM OBJECTIVES:
C THE MODEL WAS DEVELOPED TO BE USED AS A MANAGEMENT TOOL IN THE
C EVALUATION OF ALTERNATIVE MANAGEMENT STRATEGIES OF ANIMAL DISEASES
C AND PROGRAMS.IN THE ANALYSIS THE DAIRY COW IS VIEWED AS A DURABLE
C ASSET.THE MODEL SIMULATES RETURNS OF A DAIRY COW OVER A 14 YEAR
C PERIOD.SIMULATED RETURNS OF A SICK COW POST-TREATMENT ARE COMPARED
C WITH THOSE OF A POTENTIAL REPLACEMENT HEIFER TO DETERMINE IF THE COW
C SHOULD BE CULLED IN FAVOUR OF A REPLACEMENT.IF THE SICK COW IS TO BE
C RETAINED THEN VARIOUS MANAGEMENT STRATEGIES ARE EVALUATED TO IDENTIFY
C THE MOST ECONOMICAL MANAGEMENT STRATEGY.
C
C PROGRAM ORGANIZATION:
C DECANA IS COMPOSED OF THE MAIN PROGRAM,FOUR SUBROUTINES AND THE DATA
C SECTION.THE MAIN PROGRAM CALLS THE DATA-READING SUBROUTINE,RDFIXED,
C THEN IT READS SOME DATA SPECIFIC TO THE COW UNDER CONSIDERATION.
C THEN THE PROGRAM CALLS CALIMLK.THE SUBROUTINE THAT COMPUTES MILK
C INCOME PER LACTATION.THEN CALCOLF,THE SUBROUTINE THAT COMPUTES THE
C VALUE OF THE CALF BORN IN A LACTATION ,THEN SUBROUTINE CALCFED WHICH
C COMPUTES THE COSTS OF FEEDS INCURRED DURING THE LACTATION AND
C SUBROUTINE CALCHLTH FOR THE COMPUTATION OF THE HEALTH COSTS.
C THE NET FLOWS ARE DISCOUNTED,ACCUMMULATED,ANNUALISED AND WEIGHTED BY
C PROBABILITY THAT THE ANIMAL DIES IN A LACTATION,IS CULLED INVOLUNTARY
C OR SURVIVES THROUGH THE LACTATION.

C***************************************************************************
C
C DECLARATION OF VARIABLES
C
      character misc*80,HLTHST*15,SP*80
      REAL lacfac(14),seafac(12),mlkpt(7,17),FEEDS(6,9,3),HCGP1,HCGP2,
     +fccst(5),mpt(15),PCULL(14),PDEATH(14),MCSTFAC(14),MILK,CYSTCT,
     +MLKINC,avfcp,HCGCT,GNRHCT,examc,ccopen,DCPEN,prcmlk,PRCMEAT,NETT,
     +GNRHP1,GNRHP2,PANIMV,NANIMV,NET,DSTINC,ACCINC,STDINC,STDINCT,
     +mltn,cystic,tfcost,calf,YLDPL,YLDNCW,WGHT,CI,PD,DISRATE(200),
     +HCGST1,GNRHST1,T1HCG,T2HCG,T3HCG,T1GNRH,T2GNRH,T3GNRH,STDSLV,
     +STDINCC,STDINCD,STDINCS,ANNUITY(200),YLDFST,MAX,SALVG,SALVSV,
     +COWMAX,DISRT2(14),ANNT2(14),WILSTDI(2),DISNET,SDISNET,
     +SUMSIX,SUMTLV,ILSTDD,ILSTDC, DIFF(2),TEMP(2),EBV,NTST1,TINT,T2NT,
     +avmcp,nodev(2),PRMN(14),PPCULL(14)
      INTEGER Icow,IYR,lact,mnth,TMNTHS,LACLGT,I,J,K,Z,MAXLACT,MAXNUM,
     +COWLACT,COWNUM,MSTAT,ILMNC,SICK,DCSICK,LACTIM,MONTH,DMNTHS


C  READ THE FIXED VARIABLES BY CALLING SUBROUTINE RDFIXD

      call rdfixd(MISC,LACFAC,SEAFAC,MLKPT,PCULL,AVFCP,AVMCP,MCSTFAC,
     +EXAMC,CDOPEN,DCPEN,PRCMLK,PRCMEAT,FEEDS,FCCST,HCGP1,HCGP2,HCGCT,
     +GNRHP1,GNRHP2,GNRHCT,PDEATH,PRMN,PPCULL)
C
C  MAIN DATA IS READ IN A LOOP FOR EACH COW.
C  ICOW=0 FOR HEIFER, 1 FOR CYSTIC COW
```

```
C  YLDPL=MILK YIELD PREV LACT OR AVERAGE HEIFER PRODUCTION FOR THE HERD.
C  PRODUCTION IS SIMULATED OVER  4 LACTATIONS.
C  MAX IS A VARIABLE FOR THE MAXIMUM STANDARDISED VALUE FOR A POTENTIAL
C  REPLACEMENT HEIFER.
      MAX = 0.0
C
100   CONTINUE
C
      read(5,11,end=9000)icow,yldpl,ci,pd,lact,MONTH,LACTIM,WGHT,CYSTCT
11    format(I5,F10.0,2F5.0,2I5,I5,2F10.2)
C
C  WRITE COW DATA ON OUTPUT.
C
      write(6,20)
      write(6,11) icow,yldpl,ci,pd,lact,MONTH,LACTIM,WGHT,CYSTCT
20    format('-ICOW      yield    ci    pc   lact MONTH  LACTIM   WGHT
     +CYSTCT '//)
C
C  SET OPORTUNITY COST VALUES.
C
      SALVG = -500.0
      SALVGV = -1500.0
C
C  INITIALIZE SOME OUTPUT VARIABLES TO ZERO.
      CALF = 0.0
      MET = 0.0
      METT = 0.0
      DSTINC = 0.0
      HLTH = 0.0
      MILK = 0.0
      MLKINC = 0.0
      TFCOST = 0.0
      MAXNLM = 0
      MAXLACT = 0
      COWMAX = 0.0
      COWLACT = 0
      COWNLM = 0
      GNRHST1 = 0.0
      HCGST1 = 0.0
      MTST1 = 0.0
C
C  SET THE COMPUTATION FOR THE CYSTIC COW TO BEGIN AT THE TIME OF
C  THE DECISION TO TREAT- ABOUT THE THIRD MONTH.
C  AND SET THE SICK AND DOSICK COUNTERS.
      IF(ICOW .EQ. 1)THEN
      DOSICK = 2
      ELSE
      DOSICK = 1
      LACTIM =LACTIM-1
      ENDIF

C  COMPUTE THE YIELD IN FIRST LACTATION AND SET THE LOOP FOR
C  COUNTING THE NUMBER OF TREATMENTS.
C
      YLDFST = YLDPL*(LACFAC(1)/LACFAC(LACT))*(SEAFAC(1)/SEAFAC(MONTH))
      DO 155 SICK = 1,DOSICK
      IF(ICOW .EQ. 1)THEN
      MSTAT = 3
      ELSE
      MSTAT = 1
      ENDIF
```

```
      LACLGT = LACTIM
      MNTH = MONTH
      ACCINC =0.0
      STDINCT = 0.0
      TMNTHS = MSTAT-1
      DMNTHS = 0
      WRITE(6,21)
C
C  WRITE HEADING FOR OUTPUT.
C
21    FORMAT('0 LACT MNTH  TMNTHS MILK  CALF  FEEDS HEALTH     NETINC
     +    DMNTHS     DISRATE DSTINC  ACCINC   ANNUITY    STDINC  ')
C
      IF(ICOW .EQ. 0)THEN
      WRITE(6,3)SALVGV
3     FORMAT('0',46X,F10.3)
      ELSE
      WRITE(6,3)SALVG
      ENDIF
C
C  BEGIN LOOP FOR SIMULATING ANNUAL BENEFITS AND COSTS.
C
      DO 200 I=LACT,14
      YLDNOW = YLDFST*(LACFAC(I)/LACFAC(1))*(SEAFAC(MNTH)/SEAFAC(1))
      STDSLV = 0.0
      STDINCD = 0.0
      STDINCC = 0.0
      STDINC = 0.0
      STDINCS = 0.0

C
      WRITE(6,19)I,MNTH
19    FORMAT(2I4)
C
C COMPUTE RETURNS ON A MONTH BY MONTH BASIS PER LACTATION.
C
      DO 300 K=MSTAT,LACLGT+SICK+2
C
C CALCULATE MILK INCOME USING THE SUBROUTINE CALCMLK
C
      call calcmlk(YLDNOW,PRCMLK,MCSTFAC,
     +MLKINC,mlkpt,ICOW,LACLGT,SICK,MPT,K,LACT)
C
C CALCULATE FEED COSTS USING SUBROUTINE CALCFED
C
      call calcfed(ICOW,LACT,MPT,FEEDS,FCOST,TFCOST,K)
C
C INCORPORATE THE RETURNS FROM CALF AND HEALTH COST USING THE
C RESPECTIVE SUBROUTINES.
C
      CALL CALCCLF(PRCMLK,CI,PD,LACFAC,I,AVFCP,AVMCP,K,CALF)

      CALL CALCHLT(YLDNOW,ICOW,CYSTCT,EXAMC,K,I,SICK,MSTAT,LACT,
     +HLTH)
C
C
C CALCULATE THE NET INCOME,DISCOUNTED INCOME,ACCUMULATED INCOME AND
C THE STANDARDISED ANNUAL INCOME
      TMNTHS = TMNTHS+1
      DMNTHS = DMNTHS+1
      DISRATE(TMNTHS) = 1.0/(1.01**DMNTHS)
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```
      ANNUITY(TMNTHS) =(0.01/(1.0-(1.0/(1.01)**TMNTHS)))
C
      NET = MLKINC + CALF - TFCOST - HLTH
C
      DSTINC = NET * DISRATE(TMNTHS)
      IF((K .EQ. MSTAT).AND.(ICOW .EQ. 1).AND.(LACT .EQ. 1))THEN
      ACCINC = ACCINC + DSTINC+SALVG
      ELSEIF((K .EQ. MSTAT).AND.(ICOW .EQ. 0).AND.(LACT .EQ. 1))THEN
      ACCINC = ACCINC + DSTINC +SALVGV
      ELSE
      ACCINC = ACCINC + DSTINC
      ENDIF
      STDINC = ACCINC * ANNUITY(TMNTHS)
C
C COMPUTE EXPECTED RETURNS GIVEN THE PROBABILITIES OF DEATH,INVOLUTARY
C CULLING AND SURVIVAL ON LACTATION BY LACTATIONS BASIS.
C
      IF(K .EQ. 6)THEN
      STDINCD = STDINC*PRMN(LACT)*PDEATH(LACT)
      ELSEIF(K .EQ. LACLGT+SICK)THEN
      STDSLV= 500.0*DISRATE(TMNTHS)*ANNUITY(TMNTHS)
      STDINCC=((STDINC+STDSLV)*PRMN(LACT)*PCULL(LACT))
      STDINCS =((STDINC +STDSLV)*PPCULL(LACT))
      STDINCT = STDINCD + STDINCS + STDINCC
      WRITE(6,*)'STDINCT = ',STDINCT
      ELSE
      ENDIF
C
C OUTPUT THE RESULTS OF THE PROGRAM.
C
      write(6,7)TMNTHS,MLKINC,CALF,TFCOST,HLTH,NET,DMNTHS,
     *DISRATE(TMNTHS),DSTINC,ACCINC,ANNUITY(TMNTHS),STDINC
7     format(3X,I5,4X,F6.2,1X,F5.2,2X,F7.2,1X,F6.2,2X,F10.3,3X,I5,1X,
     *5F10.3)
C
C  FIND THE CURRENT VALUE OF MAX
C
      IF(ICOW .EQ. 0 .AND. STDINCT .GT. MAX)THEN
      MAX = STDINCT
      MAXNUM = TMNTHS
      MAXLACT = LACT
      ELSE
      ENDIF
C
C  FIND THE OPTIMAL PERIOD FOR KEEPING THE TREATED COW-WHERE COWMAX IS
C  GREATER THAN MAX.

      IF(ICOW .EQ. 1 .AND. STDINCT .GT. 0.0 .AND. STDINCT .LE. MAX)THEN
      COWMAX = STDINCT
      COWLACT = LACT
      COWNUM = TMNTHS
      ELSE
      ENDIF
C
C  COMPUTE THE WEIGHTED INDIVIDUAL LACTATION STANDADIZED RETURNS.
C
      IF(ICOW .EQ. 1)THEN
      IF(I .GT. LACT .OR. K .GT. LACLGT+SICK)THEN
        ILMNC = ILMNC +1
        DISRT2(ILMNC) = 1.0/(1.01**ILMNC)
         ANNT2(ILMNC) = (0.01/(1.0-(1.0/(1.01)**ILMNC)))
```

```
      DISNET = NET* DISRT2(ILMNC)
      SDISNET = SDISNET +DISNET
        IF (ILMNC .EQ. 8 )THEN
          SUMSIX = SDISNET - 500.
          ELSE
         ENDIF
          IF(ILMNC .EQ. LACLGT+SICK)THEN
           SUMTLV = SDISNET-500.
            ILSTDD = SUMSIX +ANNT2(ILMNC)*PRMN(LACT)*PDEATH(LACT)
      ILSTCC =(SUMTLV+500*DISPT2(ILMNC))*ANNT2(ILMNC)*
     +(PRMN(LACT)-PDEATH(LACT))
            WILSTDI(SICK)= ILSTDD + ILSTCC
            IF(WILSTDI(SICK) .LT. MAX .AND. TEMP(SICK).GT. MAX)THEN
              DIFF(SICK)= MODEV(SICK)-MAX
               WRITE(6,*)'MODEV',SICK,'= ',MODEV(SICK)
               WRITE(6,*)'DIFF',SICK,'= ',DIFF(SICK)
             ENDIF
C
C   COMPUTE THE EXPECTED MONETARY VALUE.
C


C
           ENDIF

      ENDIF

C
      IF(I .GT. LACT)THEN
       IF(K .EQ. LACLGT+SICK)THEN
        WRITE(6,*)'WILSTDI',SICK,'= ',WILSTDI(SICK)
       ENDIF
      ENDIF
C
C
      IF(K .EQ. LACLGT+SICK)THEN
      MODEV(SICK) = STDINCS
      TEMP(SICK)= WILSTDI(SICK)
       WRITE(6,*)'ILMNC = ',ILMNC
         ILMNC = 0.0
       DISNET  = 0.0
       SDISNET = 0.0
       SUMSIX  = 0.0
       SUMTLV  = 0.0
       ILSTDD  = 0.0
       ILSTCC  = 0.0

      ENDIF
      ENDIF
300   CONTINUE
C
      IF((ICCW .EQ. 1).AND.(I .EQ. LACT))THEN
      LACLGT = LACTIM - SICK
      ELSE
      ENDIF
C
C INCREMENT THE LACTATION AND CALVING MONTH PARAMETERS.
C
      IF((ICCW .EQ. 1).AND.(I .EQ. LACT).AND.(SICK .EQ. 0))THEN
        MATH = MATH +2
```

```
      ELSEIF((ICOW .EQ. 1).AND.(I .EQ. LACT).AND.(SICK .EQ. 0))THEN
        MNTH = MNTH +1
      ELSE
        MNTH = MNTH +0
      ENDIF
      IF (MNTH .GT. 12)MNTH = MNTH - 12
      MSTAT = 0
C OUTPUT THE WEIGHTED RETURNS FOR DEATH ,CULL AND SURVIVAL WITH THE
C TOTAL PER LACTATION.
C
C PROCEED TO THE NEXT  LACTATION.
C
200   CONTINUE
C
      WRITE(6,*)'MAXLACT = ',MAXLACT,'MAXNUM = ',MAXNUM,' MAX = ',MAX
      WRITE(6,*)'GNRHST1 = ',GNRHST1,'HCGST1 = ',HCGST1,'MTST1 = ',MTST1
155   CONTINUE
      WRITE(6,*)'COWLACT= ',COWLACT,'COWNUM= ',COWNUM,' COWMAX= ',COWMAX
      WRITE(6,*)'GNRHST1= ',GNRHST1,'HCGST1 = ',HCGST1,'MTST1 = ',MTST1
C
      GO TO 100
C
C   NO MORE COW DATA TO PROCESS,END PROGRAM.
C
9000  CONTINUE
      PRINT 9001
C
9001  FORMAT('-DONE')
      END
C
C  ********************BEGIN SUBROUTINES*****************************
C
      SUBROUTINE RDFIXD(MISC,LACFAC,SEAFAC,MLKPT,PCULL,AVFCP,AVMCP,
     +MCSTFAC,EXAMC,CDOPEN,DOPEN,PRCMLK,PRCMEAT,FEEDS,FCOST,HCGP1,HCGP2,
     +HCGCT,GNRHP1,GNRHP2,GNRHCT,PDEATH,PRMN,PPCULL)
C
C THE SUBROUTINE IS TO READ THE FIXED VARIABLES FOR THE MODEL.THE
C INCLUDE ARRAYS,TABLES,GENERAL VARIABLES AND VARIABLES SPECIFIC TO
C THE ANIMAL UNDER A PARTICULAR RUN.
C
      CHARACTER MISC*80,SP*80
      REAL LACFAC(14),SEAFAC(12),MLKPT(7,17),PCULL(14),PDEATH(14),
     +FEEDS(6,9,3),FCOST(5), MPT(15),MCSTFAC(14),PRMN(14),PPCULL(14),
     +MILK,MLKINC,AVFCP,AVMCP,EXAMC,CDOPEN,PRCMLK,NET,
     +HLTH,CYSTIC,TFCOST,CALF,RATIO
      INTEGER ICOW,YLDPL,COW,SIRE,LACT,MNTH,AGE
C
C  READ IN FIXED VARIABLES, MISC READ TO SPACE DATA ONLY
C
      READ(5,1)SP
1     FORMAT(A)
      read(5,2) LACFAC
2     format(10x,7f10.4)
      READ(5,1)SP
      read(5,2) SEAFAC
      read(5,1) SP
      READ(5,2) PCULL
      READ(5,2) PDEATH
      READ(5,7) PRMN
      READ(5,7) PPCULL
7     FORMAT(10X,7F10.6)
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```
      READ(5,1) SP
      READ(5,2) MCSTFAC
      READ(5,1) SP
      read(5,2) (MLKPT(I,17),I=1,6)
      read(5,3) ((MLKPT(I,J),I=1,6),J=1,16)
3     FORMAT(10X,6F10.2)
      read(5,1) SP
C
C  CALC UPPER BOUND ON MPT AS 25 00
C
      mlkpt(7,15) = 25000.
      ratio = (mlkpt(6,17)-mlkpt(2,17)) / (25000.0-mlkpt(2,17))
      DO 10 I=1,14
      mlkpt(7,i) = mlkpt(2,i) + (mlkpt(6,i)-mlkpt(2,i))/ratio
10    CONTINUE
      read(5,1) misc
      read(5,4) avfcp,avmcp,examc,cocpen,DCPEN,premlk,PRCMEAT
4     FORMAT(1X,7F10.2)
      READ(5,1)MISC
      READ(5,5)MCGP1,MCGP2,MCGCT,GNRHP1,GNRHP2,GNRHCT
5     format(10x,6f10.2)
      read(5,1) SP
      read(5,1) SP
      read(5,3) ((feeds(i,j,1),i=1,6),j=1,9)
      read(5,1) SP
      read(5,3) fcost
3     FORMAT(25X,5F10.3)
      read(5,1) SP
      read(5,1) SP
      READ(5,3) ((FEEDS(I,J,2),I=1,6),J=1,9)
      READ(5,1) SP
      READ(5,1) SP
      READ(5,3) ((FEEDS(I,J,3),I=1,6),J=1,9)
      READ(5,1) SP
      READ(5,1) SP
      return
      end
C*********************************************************************
      subroutine calcmlk(YLDNOW,PRCMLK,MCSTFAC,MLKINC,
     +MLKPT,ICOW,LACLGT,SICK,MPT,K,LACT)

C THE SUBROUTINE COMPUTES THE MILK YIELD FOR THIS LACTATION AND THE
C DOLLAR VALUE OF THE MILK IN THE LACTATION.MILK YIELD IS PREDICTED BY
C A LACTATION FACTOR AND A SEASONAL FACTOR BASED CORRESPONDING TO THE
C LACTATION NUMBER.MILK RETURNS ARE PREDICTED ON A MONTHLY BASIS.
C

      REAL MLKPT(7,17),MPT(16),MCSTFAC(14),
     +milk,mlkinc,premlk,YLDPL,YLDNOW,RATIO
      INTEGER Icow,lact,mnth,I,J,L,K,Z,SICK,LACLGT

C MILK IS COMPUTED AS A FUNCTION OF THE INITIAL PRODUCTION LEVEL,
C LACTATION NUMBER,SEASONAL FACTOR AND THE DISEASE FACTOR.

      RATIO = 0
C
C  CALCULATE THE LBS/DAY/MONTH MILK YIELD FROM LACTATION CURVES(TABLES)
C
      DO 100 I=2,7

        J = I-1
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```
        IF (YLDNOW .LT. MLKPT(I,17))GO TO 120
110   CONTINUE

120   CONTINUE
      RATIO = (YLDNOW-MLKPT(J,17)) / (MLKPT(J+1,17)-MLKPT(J,17))

      IF(K .GT. LACLGT+SICK)THEN
      MPT(K) = 0.0
      ELSE
        MPT(K) = MLKPT(J,K) + RATIO*(MLKPT(J+1,K)-MLKPT(J,K))
      ENDIF
      IF((ICOW .EQ. 1).AND.(I .EQ. LACT))THEN
      MILK = MPT(K)*MCSTFAC(K)*3
      ELSE
        MILK = MPT(K)*30
      ENDIF
C MILK INCOME IS A FUNCTION OF MILK YIELD AND PRICE.
C
      mlkinc = milk * prcmlk
      return
      end
C**********************************************************************
      subroutine calcclf(PRCMLK,CI,PD,LACFAC,I,AVFCP,AVMCP,K,CALF)
C
C THE SUBROUTINE CALCULATES THE PRESENT VALUE OF A CALF PRODUCED BY
C THE COW THIS LACTATION BASED ON THE AVERAGE COST OF ACALF AND PREDIC-
C MILK DIFFERENCE OF THE COW IN HER LIFETIME.
C
C
      real SUM,PRCMLK,CI,PD,LACFAC(14),AVFCP,AVMCP,CALF,EBV
      INTEGER I,K
C
C  COMPUTE THE EXPECTED BREEDING VALUE(EBV) OF THE CALF BASED ON
C  THE COW INDEX(CI) AND THE SIRE'S PREDICTED DIFFERENCE(PD)
      SUM =0.0
      EBV =0.0
      EBV =(0.5 * CI)+(0.5 * PD)
C
C  COMPUTE THE EXTRA MILK VALUE OF THE CALF DUE TO HER GENETIC
C  SUPERIORITY(MODIFIED  EQUATION BY KUIPERS,A.(1983).)
C
      sum = 0.68 * 3.813 * prcmlk * EBV * LACFAC(I)
C
C ADD ALL THE FLOWS AND RETURN THE OVERALL CALF VALUE TO THE PROGRAM
C
      IF(K .EQ. 1)THEN
      calf =0.441*( avfcp + sum) + (0.459*avmcp)
      ELSE
      CALF = 0.0
      ENDIF
      return
      end
C**********************************************************************
      subroutine calcfed(ICOW,LACT,MPT,FEEDS,FCOST,TFCOST,K)

C THE SUBROUTINE COMPUTES THE FEED COSTS INCURRED ON PER LACTATION
C BASED ON WHETHER THE COW IS DRY OR LACTATING. FOR ALACTATING COW
C FEED REQUIREMENTS ARE COMPUTED BASED ON DAILY MILK YIELD PER MONTH
C
C
      REAL MPT(16),FEEDS(6,9,3),RATIO,fcost(5),TFCOST,X
```

```
      INTEGER ICOW,LACT,I,J,K,L,Z
C
C  CALCULATE LBS/DAY/MONTH BASED ON DATA IN MATRIX.
C
      RATIO = 0.0
      IF (LACT .LE. 3)THEN
         L = LACT
      ELSE
         L= 3
      ENDIF
C
      do 430 j=1,9
        Z=j-1
C
      IF(MPT(K) .GE. 15.0 .AND. MPT(K) .LT. 30.0)THEN
        MPT(K) = 30.0
         ELSEIF(MPT(K) .LT. 15.0)THEN
          MPT(K) = 0.0
          ELSE
          ENDIF
        if (mpt(K).lt.feeds(1,J,L)) go to 435
C
430   continue
435   CONTINUE
      ratio = (mpt(K)-feeds(1,Z,L)) / (feeds(1,Z+1,L)-feeds(1,Z,L))
      TFCOST = 0
      do 440 j=1,5
         x = feeds(j+1,Z,L) + ratio * (feeds(j+1,Z+1,L)-feeds(j+1,Z,L))
          x = x * 30.0 * fcost(j)*2.0
         tfcost = tfcost + x
440   CONTINUE
C
      return
      end

C*********************************************************************
      SUBROUTINE CALCHLT(YLDNOW,ICOW,CYSTCT,EXAMC,K,I,SICK,MSTAT,LACT,
     +HLTH)
C
C THE SUBROUTINE CALCULATES HEALTH COSTS PER LACTATION.
C HEALTH COSTS ARE A FUNCTION OF MILK PRODUCTION LEVEL,STAGE OF THE
C LACTATION AND DISEASE COSTS INCLUDING TREATMENT COSTS,EXAMINATION
C COST,AND COST OF DAYS OPEN(IN THE CASE OF CYSTIC OVARIES).
C
      REAL YLDNOW,CYSTCT,EXAMC,HLTH
      INTEGER ICOW,K,MSTAT,SICK,I,LACT
C
      IF(YLDNOW .GT. 15000)THEN
      hlth = 20.0*(1.0/K)+((YLDNOW - 15000)*(0.1*0.012))
      ELSE
      HLTH = 20.0*(1.0/K)
      ENDIF
      IF((ICOW .EQ. 1).AND.(I .EQ. LACT).AND.(K .LT. MSTAT+SICK))THEN
         HLTH = HLTH+CYSTCT+EXAMC
      ELSE
      ENDIF

C RETURN TO THE MAIN PROGRAM
      return
      end
C*********************************************************************
```