SYSTEM SIMULATION MODELING OF A BEEF CATTLE ENTERPRISE TO INVESTIGATE MANAGEMENT DECISION MAKING STRATEGIES

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This is to certify that the

thesis entitled

System Simulation Modeling of
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presented by

Michael Raymond Jaske

has been accepted towards fulfillment
of the requirements for

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ABSTRACT

SYSTEMS SIMULATION MODELING OF A BEEF CATTLE ENTERPRISE

TO INVESTIGATE MANAGEMENT DECISION MAKING STRATEGIES

By

Michael Raymond Jaske

Management decision making can be greatly improved by provision of better information about alternative choices to the decision maker. The complexity of agricultural systems, and livestock ones in particular, has resulted in considerable neglect in early model building efforts to supply better information. Simulation models have the capability of surmounting many of the problems of modeling complicated dynamic system behavior. This thesis develops a simulation model of a general beef cattle enterprise to allow investigation of alternative management decision making strategies.

The model simulates the behavior of the major physical and financial variables of the enterprise through time. Although the model is intended for general use, attention has been concentrated on modeling of the land extensive cow/calf range operation. The model consists of five major components and several secondary components. Major components are (1) cattle demography, (2) forage growth, (3) feed stock accounting, (4) nutrient impacts on growth and reproduction, and (5) management decision making. The financial component is the most important component of the secondary group. Land allocation among alternative uses and crop production are not modeled and are arbitrarily specified by the user. A large FORTRAN computer program

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and subroutines accomplish this system simulation.

A highly disaggregated herd population model allows full exploration of population dynamics. Using TDN as the basic feed quality descriptor, and net energy for growth and maintenance where possible, the nutrient impact component predicts rates of weight gain and reproductive dynamics as a result of feed intake. Forage growth is modeled as a function of the exogenous weather variables of solar radiation, temperature, and rainfall. The financial component determines revenue and cost as a result of physical events and these determine the effect on profit, cash flow, depreciation, taxation, and debt levels.

The management component has been developed to provide for the needs of managers in ongoing operating decisions as well as investment planning. Detailed control variables allow realistic simulation of events of interest to managers. The interactive structure of the component, with straight forward decisions made endogenously following standard economic criteria and more complex decisions made exogenously by the model user, is implemented in a batch mode to allow creation of files storing the model's values at decision points where user control is required. A decision tree of alternative courses of action can be developed by cataloging the files created at each encounter of a decision point.

Three examples of management strategies are evaluated to demonstrate the capability of the model to assist decision makers. These are (1) early versus late calf weaning, (2) the rate of cattle herd development in investment projects, and (3) general profit maximization. These examples are discussed in terms of financial criteria.

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The thesis concludes with a summary of the accomplishments that have been realized, conclusions about the worth of the model and the demonstration examples presented, and a discussion of the current state of validation of the model along with improvements and extensions which appear to be helpful.

SYSTEM SIMULATION MODELING OF A BEEF CATTLE ENTERPRISE TO INVESTIGATE MANAGEMENT DECISION MAKING STRATEGIES

By

Michael Raymond Jaske

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This thesis has been completed with the help of many people. My major advisor, Dr. Thomas J. Manetsch, has been most helpful in reviewing various drafts, but most importantly he gave me the opportunity to find my own direction and to develop as a professional. Dr. R. J. Deans and his student Margaret Schuette are responsible for initiating this project and the cooperative effort among us has been very beneficial. Dr. G. E. Rossmiller has provided advice on economic matters and potential uses of the simulation model in economic development. Other members of my committee--Dr. G. L. Park, Dr. R. A. Schlueter, and Dr. J. S. Frame--have provided me with advice and encouragement. My wife, Marsha, has been most patient and supportive during the years of my graduate education.

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CHAPTER I

INTRODUCTION

This thesis discusses the development of a simulation model of a beef cattle enterprise and the use of this model as a tool to investigate alternative management strategies available to the operator of that enterprise. Although a general model of an individual enterprise has been developed the emphasis of this thesis lies in the land extensive cow/calf operation. Coordination of this thesis with work in the Department of Animal Husbandry by Schuette has allowed incorporation of that work in the nutrient impact component allowing considerable detail in investigation of questions of nutrient feed intake on cattle growth and reproduction. An interactive management decision making component allows the user of this model to control the decisions made which affect the long range behavior of the enterprise.

Chapter II discusses general concepts of systems, modeling, simulation and uses of simulation models. These ideas are the foundation upon which this thesis is based. Chapter III presents the general scope of the problem, reviews the relevant literature and previous approaches, and finally gives the detailed problem statement. Chapter IV gives a description of the model and its components without extensive use of mathematics. Chapter V presents the model and its components, both minor and major, in detail and lists all variable definitions in an appendix. The mathematical models used, the major assumptions made, and the exact equations upon which the computer programs are based are presented in this chapter. Chapter VI reviews the validation procedur

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procedures used to develop evidence that the model and its components properly represent their real world processes. Sensitivity testing of some model parameters is also presented to assist in identification of those capable of significantly altering the system's behavior. Chapter VII reviews the results of several demonstration examples of the capability of the simulation model to assist in various decision making evaluations. Chapter VIII presents the conclusions drawn from the construction and use of the model, reviews the results of the demonstration examples, and discusses areas of improvement and extension of the model.

It is anticipated that this thesis will be read by three distinct groups of persons--systems science professionals, animal husbandry specialists, and management personnel. Because of the widely varying backgrounds of these three groups in terms of mathematical expertise and familiarity with computer simulation studies, not all of the material presented here is readily understandable by all readers. Specific chapter groupings will be recommended for each potential audience in order to facilitate understanding. Systems science professionals should read chapters 3, 4, 5, 6, 7, and 8. Animal husbandry specialists should read chapters 2, 3, 4, 6, 7, and 8, while management personnel should read chapters 2, 3, 4, 6, 7, and 8. An Appendix is provided which lists background references of particular interest to readers not familiar with systems science who wish to become acquainted with it in more detail.

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CHAPTER II

GENERAL CONCEPTS

This chapter is written as an aid in understanding for those readers who do not have experience in systems studies or in the development and use of simulation models. Four important topics will be covered. First, some essential systems concepts will be presented; these form the basis for the entire approach used in this thesis. Second, modeling will be discussed in terms of the steps in model development, alternative modeling approaches, and useful diagrammatic conventions. Third, the idea of simulation will be briefly explained. Finally, simulation models will be examined from the point of view of the limitations and capabilities of different uses. This chapter will not be necessary for those having a systems background, or those with previous experience in simulation modeling.

What is the rationale for using the "systems approach" in studying a beef cattle enterprise? The systems approach to problem solving is a general technique of analyzing needs to determine goals and evaluating alternative ways of achieving the desired goals. It offers the manager of an enterprise an opportunity to test management decisions to increase profitability, as well as the initial planning on which an investment is based. Although systems as an organized science is relatively new, the techniques and methods are drawn from the basic engineering disciplines. Systems studies and methods were first used in the aerospace industry because of the very complex problems typically encountered: the Apollo project is a notable example. During the 1960s business applications started as manufacturers realized that complica

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complicated production and inventory problems could be analyzed and solved using a systems approach. In more recent years the scope of systems studies has broadened rapidly. Extensions to economic and socio-economic systems, especially in large aggregate models, have become common. Systems studies are also being applied to smaller scale systems such as pest management and river ecology; these can become extremely complex when the myriad of details formerly neglected are included. The remainder of this chapter is devoted to building the basic foundation for the systems analysis application of this thesis.

II.1 Systems Concepts

This section will present some basic ideas and concepts of the systems approach to problem solving. These are the philosophy on which the methodology is based, the terminology most frequently used, and common graphical methods of representing the behavior of the system being analyzed. The Appendix to this thesis consists of a specialized bibliography that should be consulted for a thorough treatment of the material presented in this chapter.

The methodology of the systems approach is based on a philosophy that views a problem globally, i.e., from the broadest possible perspective. The problem can be either one of design of a new system or of control of an existing system. To solve a problem one must first define it, but defining a problem requires knowledge of what one is attempting to accomplish. The desired goals of the problem must be

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translated into specific objectives that are to be accomplished. Knowledge of these objectives is vitally important to successful solution of the problem. These are found via a needs analysis involving all participants in the problem. If there appear to be several feasible ways to accomplish some of these objectives, then one must select from among the alternatives. Tradeoffs among various objectives must be resolved when they are in conflict. The designer, the manager, and the ultimate user should all have an opportunity to participate in assigning weights to the different objectives of the problem. This definition and selection process is highly iterative. The intent is to discover the solution which best meets the objectives, not merely to find a solution. The systems approach to problem solving is an organized methodology for developing specific problem objectives from the desired goals, and using these objectives to evaluate and select possible alternative solutions

Clarification of the terminology used in any discussion greatly assists in the communication process. A number of words and phrases have meanings specialized to systems science; these are defined below along with an example in the context of a beef cattle enterprise.

1. System--a collection of components with some form of regular interaction.

   example--the beef cattle enterprise itself

2. Causality--the concept of identifying the cause and its resulting effect, a cause precedes its effect in the time sequence of events

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example--a decrease in rainfall (the cause) resulting in a slowdown in forage growth rates (the effect)

3. Input variables--variable consciously brought into the system to affect its behavior

   example--feed crop purchases for use as cattle feed

4. Output variables--those variables which represent the result of the system's operation and of the input variables.

   example--animal sales to the market

5. Component--an identifiable grouping of relationships between input and output variables.

   example--forage growth and removal through grazing

6. Controllable inputs--inputs to the system that are controllable by some policy action.

   example--purchases of feed grains

7. Uncontrollable inputs--those desired inputs to a system which cannot be controlled.

   example--amount of water naturally available on a pasture

8. Exogenous inputs--those inputs to the system as a result of the system operating within an environment with influences on the system.

   example--cattle prices

9. System parameters--particular values affecting the operation of the system through its structure.

   example--basic photosynthetic efficiency of forage species

10. Transient--the time behavior of the outputs which result from zero level control inputs, commonly transient behavior decays toward zero with time.

    example--changing age distribution of the breeding herd when culling is stopped

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11. Steady state--the output variable behavior after all transient effects have died away

    example--the final age distribution of the breeding herd after changing effects are eliminated.

12. Asymptote--the limiting value toward which a sequence of numbers approaches.

    example--the total births of a calving season toward which the accumulated number of births approaches over time

13. Stochastic variable--a family of random variables, the elements of which are functions of some other variable, commonly time.

    example--monthly rainfall as a function of time of year

This list of terms is by no means exhaustive, but it does cover the major terminology that will be encountered in this thesis.

Graphical representations are frequently more easily understood than verbal descriptions. Systems diagrams take advantage of this perceptual characteristic of humans to present very concise systems representations. The following diagrams are general ones outlining in diagrammatic form the terms defined above.

II.2 Modeling

Modeling is the process of developing a mathematical description of the interrelationships between the input and output variables of the system. The model is the resulting description. To model an object or a process, whatever its nature, requires one to specify the most important of that which is known about it. Not uncommonly, several variables are known to be important, but the exact relationships are uncl

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are unclear. The modeling process can be very helpful simply by forcing oneself to be specific about ideas not usually articulated clearly. Much greater understanding of a process can be gained by those who attempt to model it because they are required to integrate together all known features. This section will present steps of model development, validation of the model, various approaches to modeling itself, and some diagrammatic conventions. Only models using mathematical equations will be included in this discussion because that is the type used in this thesis.

An all important first step in model development is concept selection. What is the concept we wish to model? Different concepts of the same object or process are possible depending upon the view point of the modeler. For example, consider the process of forage plant growth. All concepts of this process must interrelate the exogenous inputs of weather to the outputs of plant growth. One concept of this process could take a mass and energy balance approach using the requirements of growth: solar radiation, carbon dioxide, water, and soil nutrients. This would require development of mathematical relationships for root uptake of fluids, photosynthesis, respiration, and transpiration. Another concept could take a less fundamental view by using experimental observations to allocate the energy intake from solar radiation to growth depending upon the relative "productive quality" of water, temperature, and soil conditions. A model based on the first of these concepts would be able to examine

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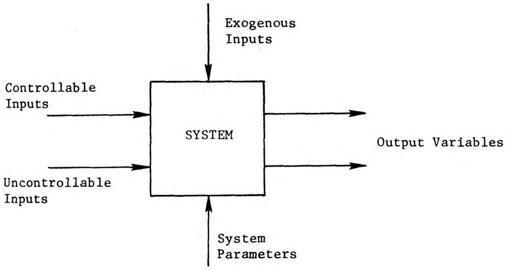

Figure 2.1 General system diagram

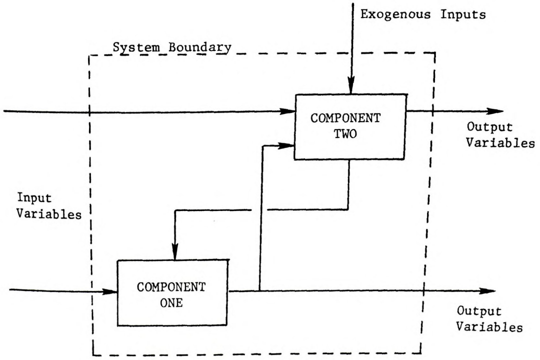

Figure 2.2 System diagram illustrating multiple components

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certain aspects better than the second, but by being more comprehensive it would be harder to develop. It would be more likely to run up against the unknown in the biochemistry of growth. These two concepts of plant growth would be used for different types of investigations requiring different levels of detail of the process. If a highly detailed model is desired, but the data to provide parameter values and variable relationships is unavailable, then the structure of the detailed model can be developed using crude working guesses until better information can be incorporated into the model. Selection of the concept, then, is important for it should be compatible with the use of the overall model one is developing.

Once the concept has been selected, then the model itself must be developed. Here one must be careful to include variables and relationships which are relevant; one should exclude variables and relationships which are irrelevant. Both are equally important. The reason for this is simply that time and energy can be saved by excluding variables and relationships which have no direct bearing on the process being modeled. For example, in a model of the forage growth process, solar radiation, temperature, rainfall, and soil nutrients are important. Relative humidity has some effect on transpiration, but in the overall process of growth it is relatively unimportant and may be excluded. Relative humidity is irrelevant in this case. Variables and relationships which are pertinent should be included; in general, those not pertinent should be excluded from a model.

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A common discovery in models composed of a number of components is that the individual components may be known rather precisely, but the interactions between them are indistinct. This is partly a result of increasing specialization in research, and partly from an inability of human beings to grasp the whole picture of what is happening in a large and complicated process. Fortunately, the use of the systems approach in multidisciplinary applications has alerted a number of people to this tendency in research, and one can hope that these gaps are soon eliminated.

A basic decision to be made early in the model development process is whether the model will be broken up into components or developed in its totality. From a mathematical and computational viewpoint it would be better for the entire model to be developed at once. This is not the usual method. Most frequently a model can be, and is, divided into separate components with each component developed separately. The component model interactions can be remembered easily with the aid of diagrams such as Figure 2.2. An advantage to component development is that concept selection is easier for a less comprehensive process. Other advantages are the ability to use component models developed elsewhere, and the ability to test the model much sooner than if the entire model were developed at once. The last reason is particularly important in validation of the model. The model developed in this thesis follows the component organization pattern.

Validation of the completed model is one of the most important steps in its development. Validation is the basic process of verifying

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that the model correctly represents the real world it attempts to describe. One can never be fully satisfied that the model is totally correct, but use and experience with the model can bring confidence. Generally validation can be assured by checking that the model is logically consistent, follows intuitively obvious patterns, and is able to track historical data. In many instances there is no historical data to track, however, and confidence in a model's validity can only be gained with use. When the model is of an existing system of which information can be gathered, then a model can be validated by prediction of the future. This approach works well in business management models as the system--the business--is monitored frequently, and data is regularly collected. Confidence in the validity of the model is gained when the model and the real world agree. When they do not agree then the model can be improved by using this newly recorded historical information. Only when a model has passed the validation stage should it be considered an adequate description of the system it represents.

Two final steps in the model development process are sensitivity testing and stability analysis. In some senses these are both means of checking the validity of a model, but they go beyond merely that. Stability analysis and sensitivity testing are procedures whereby individual and groups of model parameters are adjusted and the model outputs observed. Sensitivity of a parameter is said to exist when small changes in the parameter are followed by large changes in the output variables. In the sense of validity testing the model behavior should mat

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should match the real world. In many cases, the parameter in the real world is unknown, so the knowledge that it is sensitive in the model cannot be used to validate the model directly. This information is very useful, however, in directing the research going on in this area. Sensitivity of a parameter indicates its importance in the operation of the system; if past and present research have overlooked this parameter, then redirection of efforts should be beneficial. Stability of a model or a particular parameter set is said to exist if transient fluctuations induced by sudden input changes diminish, so the model outputs adjust to a steady state. This aspect is particularly important in designing systems or in determining policies for controlling existing systems; undamped oscillations are usually very undesirable behavior. As an example, excessive seasonal fluctuations in herd size would be undesirable. As with formal validity testing, the information gained in sensitivity testing and stability analysis is used to verify that the model is correct or to improve the model.

There are several approaches to modeling that can be selected by the modeler depending upon the system and the intended use of the model. A major characterization of a model is whether it is static or dynamic. A static model is one in which time plays no role; the model only describes variable interrelationships at one instant in time. For example, a static model is the optimization of crop sales and purchases for feeding uses at crop harvest time. A dynamic model includes time; variables may change their values from one instant to another. Even the relations between variables can change with passing time. An example of a dyna

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of a dynamic model is the relation between quantity of feed consumed and amount of weight gained in growing cattle. Another classification for models is "black box" versus structural. "Black box" models essentially deal with input and output variables; the inner workings of the real world process are useful only as a guide in selection of variables to use. This approach can only work if historical data are available from which input/output relationships can be determined, for example by regression analysis. Structural modeling derives its name from models which incorporate the structure of the real world. Structural modeling is more complex than "black box" modeling, because frequently the exact structure is unknown. Nevertheless, structural modeling is the approach used when feasible because greater confidence in the model's representation of the real world exists.

No model will ever be perfectly representative of the process it seeks to describe. Man's knowledge of the world is too limited for that to occur. Even the totality of man's understanding may not, and probably will not, be included in a model. There is simply too much information to use, and the relation of the parts to the whole are indistinct. One must always work with models that are imperfect in some way. As human understanding grows and is incorporated into models, they will perform better and have fewer shortcomings. Even imperfect models are still valuable because they are so much better than no model at all. This last point bears repeating; generally models are so much better than no model that the imperfections are gladly t

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gladly tolerated. Decisions based on use of a model will be very useful and correct provided the limitations and imperfections of the model are recognized.

Decision making is a process which involves uncertainty. This uncertainty arises from lack of understanding of the process in question, sampling errors in the data collected to represent the real world, and the presence of stochastic variables. Imperfect models are a result of this lack of understanding of the process, or perhaps conscious exclusion of factors thought to be irrelevant. Proper qualification of the predictions of models, and experience in using a model should reduce the uncertainty due to model imperfection. This still leaves the basic sources of uncertainty in decision making. These can be partially overcome by certain statistical methods (Monte Carlo usage of models[1]), but never completely eliminated. In short, decision making will remain risky.

Modeling is greatly assisted by graphical aids that present concise visual representations of the interrelationships among variables. The human eye can readily discern the multiple interactions between variables in graphical form; whereas it is much more difficult to observe these relationships in a series of mathematical equations.

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1. Hahn, G.J., "Sample Sizes for Monte Carlo Simulation", IEEE Transactions on Systems, Man, and Cybernetics, No. 1972, pp. 678-680.

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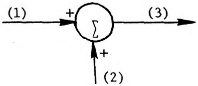
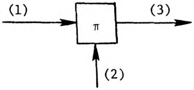
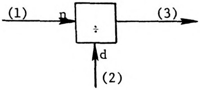


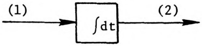
add quantity (1) to quantity (2) to get quantity (3)



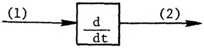
multiply quantity (1) by quantity (2) to get (3)



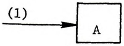
divide the numerator (1) by the denominator (2) to get quantity (3)



integrate quantity (1) to get quantity (2)



differentiate quantity (1) to get quantity (2)



take the value of quantity (1) to use at location A

Figure 2.3 Block diagram symbols for mathematical operations

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II.3 Simulation

Development of a model as a mathematical description of a system is an extremely useful and beneficial undertaking, but it is only the first step. Solving the equations that make up the model is the next step. As the size and complexity of models increase, the difficulties in finding a solution become greater. While several possible methods are theoretically available for determining a solution, the one selected is nearly always closely related to the size of the problem. Models that are amenable to analytic solution are generally very small; for this reason modeling was not a very well-developed study before the introduction of the modern digital computer. Simulation is a particular method of solution for a model which employs the computer.

A simulation model is a further abstraction from the real world, beyond a mathematical model, because certain approximations have to be made to make the mathematical model solvable. The most important approximation is one dealing with the time dynamics of a model. The infinite number of points lying between the starting and stopping times would present an impossible task if each were to be solved. A simulation model uses discrete time instances to approximate the continuous time which actually exists. Using discrete instances in time makes the number of points where the model is to be solved finite, and thus open to reasonable computation. Simulation, because of its ability to easily handle time dynamics, is the method of model solution frequently chosen when a model includes time.

The use of discrete time in place of continuous time is an approximation that inevitably introduces error into the solution that is obtaine

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is obtained. The size of this error is generally a decreasing function of decreasing step size (the interval between time points used). The number of steps required is inversely proportional to the step size, as is easily shown. The modeler is then confronted with a classic tradeoff; a tradeoff between simulation error and cost of running the model. There is no best step size to use, as a widespread rule of thumb calls for the smallest step size the project budget can afford. Another criterion frequently used employs the information obtained from running the model with successively smaller step sizes until an asymptote is reached for an important output variable. By assuming that the asymptote value is correct, one can choose the step size giving a value within the desired range of error. The following figure illustrates this idea.

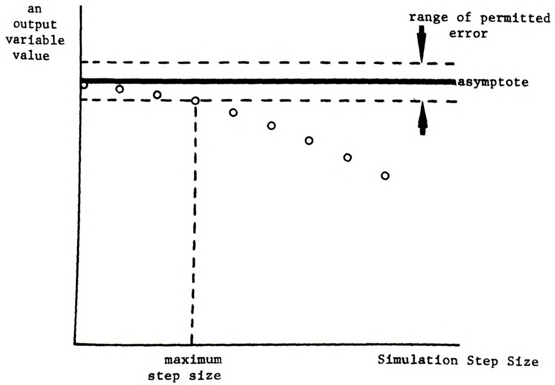

Figure 2.4 Relation between simulation step size and simulation error

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Simulation offers an advantage as a method of model solution because it is able to utilize the organization pattern of computer programming. A program is the main section of instructions directing the computer to perform specific operations. A subroutine is a secondary section called from the main program. Simulation can be handled as a program with subroutines as components. Changes in component models then mean changes in the subroutine simulation models. A model can be made operational rather quickly by inserting dummy subroutines that have the proper interaction and connections, but which may not actually perform any calculations or have a meaningful effect. Debugging of each individual subroutine is much easier than would be debugging for one single program model. This advantage is another practical reason that the model development process uses component models more often than large integrated models.

Simulation is then, first of all, a method of determining a solution to the mathematical model. In practice, a simulation model is a further abstraction from reality because it makes approximations that need not be made in the mathematical model. There are tradeoffs to be evaluated and made, mainly between simulation-induced error and cost of running the model. The advantages of component models in reducing the debugging time required are an asset to simulation. Finally, simulation is an extremely valuable technique for developing solutions to models possessing time dynamics.

II.4 Uses of Simulation Models

Simulation models can be used in a wide variety of ways. Important among them are testing specific cases, running "best versus

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worst" cases, Monte Carlo applications, and optimization of objective functions. The goals of the user, the available budget, and the characteristics of a particular use are all important elements in selection from among these. This section will discuss alternative uses, the decision criteria for choosing among them and the limitations, capabilities, and costs of each. Costs will be viewed primarily in terms of the number of simulation runs required for that use.

A fundamental use of simulation models is testing alternative parameter and input variable values to determine the outcome. This use allows a very creative interaction between decision makers and the model as they are able to test various ideas and intuitions. A major benefit that occurs is the learning experience on the part of the decision maker as he gains a better feeling for how the system works. The ability to interact with the model, learn from previous trials, and try new values not previously felt helpful is very valuable. In this use the simulation model functions as a tool of the decision maker, extending his ability to evaluate the outcome of particular policies.

An example of this use of simulation models can be found in a model of cattle grazing on natural pasture. A management policy over stocking rates is necessary to maximize the effective use of forage growth. A ranch manager can experiment with different stocking rates, and evaluate their effectiveness by using the weight gain of the cattle at the end of the season as the desired output variable. The manager can gain a better understanding of the grazing process by using the simulation model to test his intuition and the traditional methods of grazing control.

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This first use of simulation models is extremely easy to organize. The cost is quite low, since only one run is required for each test case. A limitation is that a single run of a deterministic model says very little about the likelihood of that outcome if there is any randomness in the real world system. If randomness has been incorporated into the model to reflect the real world, then a single run is not sufficient to allow choice between alternative values of parameters or control variables. An additional limitation is that one may be uncertain how to go about modifying the choice of control variables to improve upon the outcomes of a previous run.

Perhaps the easiest way of dealing with aspects of randomness in a simulation model is to devise the worst and best cases of inputs that could be encountered. By running the model with these two cases, one can determine bounds on the outcomes that should not be exceeded in the real world system. All other outcomes will be contained within the "envelope" determined by the best and worst cases. This method is only slightly more difficult to use than the first. A limitation is that "best and worst" cases may be difficult to determine, especially when there are multiple sources of randomness in the real world system. Another limitation is that one still does not know the most likely outcome, only the bounds on the outcomes. Costs are quite low for this use of simulation models, since only two runs are required to evaluate each parameter or input variable desired.

A much better method of dealing with randomness in the model is using the simulation model in a Monte Carlo mode. This requires that the probability distributions of each source of randomness be known; perhaps a difficult requirement to meet. A run of the simulation model is made wi

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is made with particular values drawn from properly random sources for each stochastic variable. All output variables of interest are recorded. Another run is made with a new set of random variables, again drawn from the proper distributions, and the outputs recorded. After a sufficiently large number of runs have been made, the statistics of the outcomes can be computed with confidence. Mean and variance would be the most important. These computed statistics can be used to develop the confidence intervals of the policy variable or parameter under study. The major difficulty with using a simulation model in a Monte Carlo mode is the large number of simulations required to properly determine the statistics of the outcome. The cost of Monte Carlo analysis for very large simulation models is frequently so high as to be prohibitive.

The final category of simulation model use is optimization of specified parameters or control variables. This method can provide very beneficial results when an objective function can be specified for minimization or maximization. Optimization is very important in design of new systems. In problems of management policy or control optimization of those policies, the optimized values should result in the best system operation possible. A major difficulty with optimization of simulation models is the large number of simulation runs required: the same difficulty with Monte Carlo analysis. The cost of the required runs may preclude use of optimization. Another limitation of optimization in simulation models involves models that have unspecified or arbitrary exogenous inputs. Specification of that input allows optimization to be performed, but the values obtained as optimal

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as optimal are conditional on the specific exogenous input used. If another value is encountered, then the "optimal policies" may not be optimal at all.

The objectives of the system study are the most important aspect in deciding which way a simulation model is to be used. For example, let us reconsider the cattle ranch possessing natural pasture. One objective could be to determine the most likely weight gain of cattle, with a specified stocking rate subject to the stochastic variables of rainfall and temperature which influence plant growth. A third objective could be to optimize total revenue by controlling stocking rate and timing of animal sales. Each of these three objectives of a study would use the same simulation model, but in different ways.

Cost is an important factor to consider when making the decision about the way a simulation model is to be used. It should also be considered from the start of the entire modeling process, as the form and content of the model should be guided by the ultimate goals of the system study. If an objective can only be achieved by use of Monte Carlo analysis, for example, and the budget is tight, then the content of the model, or sometimes its depth, can be altered. An idea to keep in mind throughout is the relationship between the cost of the entire system study and the benefits obtained from it.

II.5 Summary

This chapter has discussed the systems approach to problem solving, some topics of systems science, and simulation models. A review of the systems approach is, once again, an organized methodology of problem solving that seeks to achieve the ultimate problem goal by

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selection of a solution which best meets specific objectives derived from the goal. A systems approach works best where the process and objects under study are well enough known that mathematical relationships among variables can be specified. Another requirement for successful application of the systems approach is that adequate decision making power exist to carry out the solution, whether it is a problem of planning (design) or of management (control). The systems approach utilizing simulation models is not perfect. The models developed for the system under study can never be made perfect. The results they predict must be viewed with an eye to their imperfections. On balance, however, the systems approach is a valuable technique for analyzing problems and developing solutions to them.

By necessity the coverage of this chapter has been very rapid and it has only touched upon the high points of these topics. If the reader is interested in pursuing these subject areas in greater detail, then the references listed in the Appendix are an excellent source of introductory information.

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CHAPTER III

THE PROBLEM STATEMENT

This chapter will present four topics: the general description of the problem, a review of the literature, a rationale for selection of the simulation method, and the detailed problem statement.

III.1 General Description of the Problem

This thesis is a study of a beef cattle enterprise: a farm or ranch operation involving the breeding, growing, and selling of cattle for slaughter. There has been a steady historical progression of specialization in the industry to either breeding or fattening. Moreover, the availability of low-cost grains, chiefly corn, has led the fattening operation to lose its requirement of a land base. Feed lots are the result. Management of such feed lots has been extensively studied in recent years. The cow/calf operation, which is important in the production of feeder calves, has received little attention. The exception to this rule has been better weight gaining characteristics. The current depression in the beef cattle industry, due to both low cattle prices and the world food supply problem, is causing rethinking about the organization and methods of operation of the entire cattle industry.

This thesis concentrates its attention on a specific type of beef cattle enterprise: one which is characterized by a land-extensive cow/calf organization. Further, this operation is

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to be small enough to have no market effect from either its sales or its purchases. That is, prices remain unchanged by its activities. The scale of operation is sufficiently large, however, that the methods of systems and simulation can be profitably applied to this individual enterprise. Rough bounds on the number of breeding cows for this operation might be 50 to 1,000 animals.

This thesis also concentrates on particular questions of management of the enterprise. Management is an area that has not received extensive study at the scale of the overall system operation. Individual aspects of production and certain forms of production efficiency have received the bulk of the analysis here to date. This thesis will not make any analysis in the areas of genetics, allocation of land to alternative uses, by-product or destination marketing, or production of crops (except grazing forages). The emphasis of this thesis is on study of management policy in the areas of grazing, breeding, timing of sales, and general herd management.

Part of the reason why study of the management of this enterprise is so attractive is the general low level of mathematics used in traditional practices. A major problem in the past has been a lack of predictive capability. Extrapolation of past trends has been a dominant method employed. This is not sufficient when the dynamics of the beef production process have delays approaching two years. Another problem has been uncoordinated analysis of "separate" aspects of production, rather than an integrated analysis of the whole. This tendency has lead to dominance of certain types of emphasis, such as

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genetic manipulation. A general characteristic has been the dominance of husbandry practices and recommendations over economic considerations. Some typical problems unanswered by traditional management practices are pasture management to maximize efficient forage use, proper feeding levels to improve net profit, and the proper response to changing market conditions. This thesis seeks to contribute to the solution of these past problems and to increase the level of management performance.

III.2 Review of the Literature

An extensive literature discussing the beef cattle enterprise exists. Much of it is characterized as non-quantitative explanations of various subprocesses and reports of experimental observations. To a large degree, this literature is spread among various specialized disciplines such as animal nutrition, genetics, crop sciences, agricultural economics, and physiology. Relatively few studies have viewed the beef cattle enterprise as a system and rigorously analyzed it from the systems science point of view. The quantitative studies which do exist have taken three broadly distinct approaches; namely, analytics, optimizing, and simulation. Of these, only a minority use the simulation approach; the one seeming to offer the most potential for significant gain in this complicated, involved process of beef production by individual enterprises.

The remainder of this section will review the previous work in the area of mathematical representation of, and management control over, beef cattle enterprises. The three approaches of analytics, optimizati

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optimization, and simulation will each be discussed as a separate unit, although there is some overlap between them.

The Analytic Approach

While a strict definition for analytic would include all of the studies referenced here, the term is used to describe those which are limited to functional representations between variables. There are some areas in which the analytic approach has been most prevalent: tutorial papers, analysis of data to determine values for relationships between variables, and attempts to offer advice to management.

Representative of tutorial papers designed to present material new to the readership are development of general crop and livestock response functions[12], traditional descriptions of the cattle growth process[5], and the use of marginal analysis to optimize feedlot rations[4]. Uses of analytics to develop mathematical relationships from experimental data are too numerous to mention in detail. Several examples will serve as illustrations: algebraic growth models from cattle age-weight data[6], comparison of calving performance between drylot and pasture[37], and comparison of traditional versus modern range practices in Argentina[13]. Carpenter's paper[9], developing an algebraic growth model, is typical of analytic means of offering advice to management over questions in the production process.

The simple analytic approach to studies of the production process is inadequate for such complicated systems as this enterprise. While the analytic approach is not used appropriately in studies of the overall enterprise, it does continue to have value in determining the relationships between variables from experimental data.

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The Optimization Approach

As a general technique, optimization has been extensively used for the last three decades. Linear programming, dynamic programming, and nonlinear programming are some important methods of optimization. The usual agricultural application of these techniques has been in determining the best combination of feed inputs to maximize economic return in beef cattle feedlots[29,53]. Long, et al.,[33,34,35] have used a simulation model in an optimizing mode to study the effect of cow size on productive efficiency in drylot and pasture operations. Schwab[49] has used linear programming to optimize the entire range of resources used in a cow/calf operation.

The majority of applications of optimization in beef production have employed linear programming as the optimization technique. This method has certain restrictions which limit its usefulness in studying dynamic processes. Linear programming requires that the variables be linearly related, and that the relationships not be functions of time. A model that can be optimized using linear programming cannot provide an adequate description of the population and reproduction dynamics of a breeding cattle herd.

All optimization algorithms possess some type of objective function that is either maximized or minimized. While there is no doubt that the optimized variables are optimal for that objective function, there is doubt that the objective function correctly specifies what an enterprise manager wants optimized. For example, an important characteristic to some managers might be a flexibility of operation which allows some room to maneuver if expected conditions do not materialize. An objective function cannot measure an operations flexibility.

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Additionally, the usual methods have trouble with exogenous variables that are arbitrary or stochastic. For these reasons, optimization is not a method of analysis which provides a way of solving all of the problems facing an enterprise manager.

The Simulation Approach

Simulation is a method for developing solutions to mathematical models. Because of its ability to handle time dynamics, simulation is frequently used where time is an explicit part of the problem. The majority of uses of the simulation approach in beef cattle studies have been macroeconomic in scale. Initiation of economic development by using the cattle industry[26,31,42,43] and government policy analysis in the agricultural sector are well represented in the literature. The World Bank has used this approach for several years in evaluating the potential value of economic development projects concerning the cattle industry[10].

Simulation of beef cattle at the enterprise level is beginning to appear more frequently in the literature. A pioneering work by Halter and Dean[23,24] studying management in an integrated range/feedlot operation appeared in 1965. Cartwright and Long of Texas A&M University have participated in a number of works which concentrate on questions of cow phenotype optimization using a simulation model of cattle energy requirements[28,33,34,36]. Witz[54] has applied simulation to the feedlot ration optimization problem, while Afzal[1] has studied inventory modeling to respond to drought conditions. Many more references could be cited, but these serve as illustrations of the aspects of a beef cattle enterprise that been studied using the simulation

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simulation approach. Joandet[1] has recently published an extensive bibliography of simulation applications involving beef cattle production.

III.3 Rationale for Selecting the System Simulation Approach

This thesis will use the system simulation approach in analyzing a beef cattle enterprise. Simulation was selected because it offers the greatest potential for understanding and solving the model of the process as involved as production of beef cattle. What are the characteristics of the enterprise that are so troublesome as to require the simulation approach? Most important are the time delays inherent in the growth process. In the U. S. the time required from conception to marketing for slaughter animals may range from 11-30 months. Not only are time delays present, but the length of these delays is a variable which is partially under the control of management. Feed intake rates are an important control variable affecting growth rates. Feed intake also governs the reproductive characteristics of both mature cows and growing heifer replacements. Reproduction, then, is also a dynamic process. In short, the entire herd population is in a state of dynamic flux. Herd population dynamics is a major complexity of the beef cattle enterprise requiring the power of the simulation approach.

A similar source of complexity is the decision making that controls the enterprise's sales and purchases. Decisions involving breeding, because of the delay length in the growth process, will not affect sales revenue for nearly a year. The proper price to use in decision

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[1] Joandet, G. E., and T. C. Cartwright, "Modeling Beef Production Systems," Journal of Animal Science, Vol. 41, No. 4, 1975, pp.1238-46.

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making is that which will be in force when the product is sold. Management decisions are conditional on the stream of expected prices that are to occur over the interval between the present and the anticipated sales date. To further add to the trouble of the enterprise decision maker is the well known volatility of agricultural prices. This implies that price expectations change rapidly. Control over the beef production process is very complicated and uncertain; this is another powerful impetus toward using the simulation approach.

Other studies of beef cattle have developed partial representations of the production process as a way of decomposing the system into more manageable pieces. These studies cannot, however, be aggregated together to form proper recommendations that are generally applicable. While simulation of the production and management dynamics of the enterprise is possible, it is not easy. Very long lead times are required to model and then simulate these processes. Furthermore, simulation models can never be perfect because of the approximations necessary to determine the solution. The following section will describe in detail the exact problem that this thesis will study.

III.4 Detailed Problem Statement

The system to be analyzed here is a beef cattle enterprise. Such an enterprise can be characterized as being land extensive, involving breeding of cows for calf production, and producing a significant proportion of the nutrient requirements of the herd through forage growth. It is of such a scale that it can be treated as an atomistic economic entity.

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The problem addressed by this thesis is the construction of two distinct groups of components of this beef cattle enterprise. First, this thesis develops a dynamic simulation model of the enterprise itself. This includes models for the four major components of the system: cattle demographics, forage growth, feed stock accounting, and nutrient impacts. Second, this thesis develops an interactive management algorithm which allows the user to investigate very detailed management control policies for ongoing operational decision making or for investment planning. This algorithm is structured so that the manager can evaluate alternative strategies to cope with the effects of exogenous variables on the enterprise. Three examples of the capability of the model to assist decision making for ongoing decisions and investment planning are presented.

The simulation models of the four components of the enterprise are designed to be useful in analyzing various management policies to control the cattle herd and related processes. This requires disaggregation to a level such that the herd can be controlled as discretely by the user as could the manager himself. This also requires that the control variables of the model be devised so that a manager's actions can be simulated. Since a major weakness of previous simulation models of beef production enterprises has been a lack of population dynamics[2], and since these are required to correctly evaluate some herd control policies, the demographic model fully develops herd population dynamics. Introduction of herd population dynamics requires that cattle nutrition and reproduction dynamics[3] be included to

[2]Ibid., p. 1243.

[3]Developed by Margaret Schuette in partial fulfillment of M. S. requirements, Department of Animal Husbandry, Michigan State University.

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effectively and correctly describe births and deaths. The forage growth and feed stock components are constructed with the appropriate management control variables to allow the entire spectrum of management decision making to be exercised. These four component models represent an adequate description of the physical processes of the enterprise to allow realistic simulation of the system behavior through time. Several secondary components are developed to accomodate the non-physical aspects of the enterprise; an example is the financial component that determines the financial effect of purchases, sales, and other activities.

The management algorithm has certain unusual requirements which stem from the nature of the simulation models of the physical processes of the enterprise. As an example, the cattle demography component model maintains populations on a very disaggregated basis. Many control variables must have the same level of aggregation, thereby requiring many values to actually control herd populations. This large number of effective control elements among a number of variables has the effect of eliminating all optimization techniques because of the extremely high cost of their use. Management control, then, is exercised exogenously when certain decisions are required. This necessitates an interactive control algorithm, but since the usual source for computer interaction--the teletype--is ruled out because of the large number of control elements that must be inputed, an interactive batch mode of operation of the model has been devised. A way to control the model's simulation through time is developed which allows stops and restarts of the simulation whenever required. A beneficial feature of this interactive management algorithm is that multiple

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that multiple management policies can be evaluated, and the "best" used as the base from which the simulation is restarted. Use of this algorithm results in a time simulation which is a series of short runs, inputing control variable values as required by the particular decision to be made.

Specific Component Requirements

The four components representing the physical processes of the beef cattle enterprise must meet certain requirements. A requirement common to all is that each be dynamic, because a major element of the model is the inclusion of time in an explicit manner. A second requirement common to all is that the component models contain the control variables that allow the manager's decisions to direct and influence the physical processes of the components. A third common requirement is that each model be constructed in a sufficiently disaggregated fashion that a real manager's decisions can be simulated in the behavior of the model. These general requirements and the specific requirements outlined below must be met if the objectives of this system simulation are to be realized.

The individual requirements of the component models will be briefly summarized by listing the processes that each component model must contain. The cattle demography component must contain:

(1) age, sex, and function disaggregation of the cattle herd,

(2) births, deaths, and transfers of herd members,

(3) birth rates a function of breeding activities,

(4) weights for each herd subpopulation grouping.

The forage growth component must include:

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(2) quantity and quality of forage disaggregated by land areas which are homogeneous,

(3) grazing as a means of forage removal,

(4) mechanical harvesting as a means of forage removal,

(5) grazing consumption and wastage a function of stocking rates.

The nutrient impact component must include:

(1) determination of weight gains for herd subpopulations based on the difference between energy consumption and maintenance energy requirements,

(2) determination of the onset of estrous cycling in young heifers as influenced by nutrition from birth,

(3) dynamic energy requirements for mature cows as related to reproductive condition, i.e., lactating, breeding, and stage of gestation,

(4) determination of energy intake of cattle from multiple feed sources with individual TDN characteristics.

The feed stock accounting component must include:

(1) accounting for current feed stock levels as a function of purchases, sales, production, cattle feeding, and waste,

(2) feed stock losses from such sources as spoilage, handling, waste, and pest contamination,

(3) determiantion of the feed stock TDN value for individual feed stocks with particular rates of TDN decline over time.

The four physical components' requirements, as outlined above, are derived from the basic intent of this thesis to develop a system model that includes population dynamics, and that is capable of offering realistic simulations that are useful to enterprise managers.

The managèment decision making component has two general requirements in addition to numerous specific ones. First, the decision making algorithm must itself be dynamic to control the physical component models which have included the dynamic elements of their processes. Second, the component must include the correct control variables to

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variables to allow evaluation of realistic strategies to cope with actual operating conditions. The specific decision elements required of the management algorithm are:

(1) timing and quantities of cattle sales and purchases,

(2) separate feeding rates for each herd subgroup,

(3) timing and level of feed stock sales, purchases, cattle feeding, and production,

(4) control over stocking rates in the individual land parcels,

(5) control over stocking rates for the individual herd subgroups,

(6) timing and level of mechanical harvesting of forage,

(7) control over the timing and degree of breeding, culling, and weaning.

These requirements, both general and specific, stem from the stated intent of this thesis to develop a simulation model that can be used to investigate alternative strategies of management response to changes in the environment in which the enterprise operates.

The decision maker must make specific decisions based on the information that is known to him at the time. When the simulation pauses for exogenous control inputs, the following criteria should be available along with useful state variable values:

(1) accumulated cash flow to date,

(2) accumulated net profit to date,

(3) current levels of short and long term debt,

(4) current level of working capital on hand,

(5) production efficiency measures, such as the ratio of the weight of cattle sold over the weight of feed used.

In addition to the requirements of each of the components that have been discussed, the system model must accept certain exogenous variables that have strong influence on the system. Three weather variables-

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variables--solar radiation, average daily temperature, and rainfall--must be accepted because of their importance to forage growth. Since the production and use of feed stocks is important in beef cattle enterprises--yet this modeling effort does not include the decision to plant and harvest crops--the amount and quality of feed stocks harvested must be accepted as exogenous variables. Expected prices of cattle, production resources needed, and feed stocks must be from an exogenous source. These exogenous variables are the major source of uncertainty in the operating environment of the enterprise; the management strategies that the model will be able to evaluate are aimed at perfecting responses to fluctuations in these variables.

The following chapter will describe in general terms the components developed to meet the stated requirements of this chapter. Chapter V will discuss these same components, but in the full mathematical detail needed to completely understand how they operate and the basis for their structure.

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CHAPTER IV

GENERAL DESCRIPTION OF THE MODEL

This chapter will provide a general description of the model that was constructed to meet the requirements of the problem statement. The processes that have been modeled and the variables used in the model will be discussed for each of the components. The general organization of the model will also be reviewed. Chapter V will cover the same material but in more explicit detail, by developing the mathematical relationships that are implemented in the computer programs. The present chapter will be limited to discussion of the modeling of components in verbal terms.

IV.1 General Organization

Chapter III enumerated the four components of the system model that represent the physical processes involved in a beef cattle enterprise; these are the cattle demography component, the forage growth component, the feed stock component, and the nutrient impact component. Further, the management decision making that controls the enterprise constitutes another component. These are the five major components of the enterprise system that will be covered in this thesis. A land component, which would be required to fully investigate the entire spectrum of possible enterprise operations, is not included here. Figure 4.1 is a general system diagram illustrating the major physical

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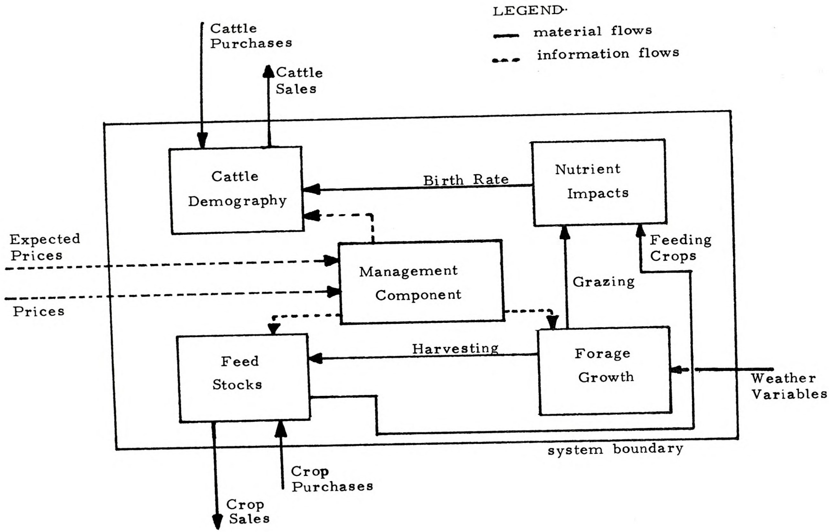

Figure 4.1 General system diagram for the beef cattle enterprise

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and information flows among components. If also shows the transfers of information and material across the system boundary.

The component with the most central impact is cattle demographics. Three major processes are represented within this component. The first is the birth of calves. This is a function of the breeding policy of the manager, the age distribution of the mature cow herd, and the nutrient intake of breedable females. The second major process is the death of animals. Deaths are attributed to old age or to premature events, such as disease or accident. The final process that this component includes is maturation of animals within the herd. Maturation will be described using the variables of age and weight.

Another important component is that of forage growth. This component must represent the growth and harvest of forages on a dynamic basis; i.e., over the growing season. Plant growth is a response to the exogenous variables of weather--solar radiation, average temperature, and rainfall. More important than actual rainfall is the level of soil moisture that is available for the root system to transport up to the leaf structure of the plant. Soil moisture must be determined through the influence of evaporation and percolation of water down beyond an effective depth reachable by roots. Digestibility of forage is another important factor in determining the nutritional impact of grazing. Grazing and mechanical harvesting are the methods of forage removal that are included in this forage growth component model.

Another component of the enterprise model includes feed stocks. This aspect of the model is less complicated than any of the others, because re

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because relatively little is involved other than accounting for various feed stock activities. Feed stock purchases and sales are determined exogenously through the interactive management component. Feed stocks used as cattle feed are a result of the level of feed allocation to the herd and of the distribution of that allocation among the possible crops. Feed stock losses are also determined in this model. Crop production, although exogenously determined in this particular system study, is also a factor affecting the overall level of feed stocks. The last element of this component model is determination of the total digestible nutrient (TDN) value of the feed stock. TDN is used as the index of nutrient value because it is a system of measurement which has been widely accepted for many years. This long tenure means information in TDN is abundant.

The nutrient impact component develops the effects of feed inputs on the cattle herd. The major processes included here are growth of animals through weight gain and reproduction resulting in births. The growth process is highly influenced by the quantity of digestible nutrients consumed by cattle. The requirements of body maintenance and of growth are met differently by the same feed input; this requires that the energy values for weight maintenance and weight gain be available for each feed stock consumed. When the requirements of body maintenance are fulfilled, any excess energy intake can be applied toward growth or toward other production processes. Reproduction is quite responsive to energy levels available to the breeding females, especially in young heifers being brought into the breeding herd for replacements. The physical processes of estrous cycling in females, both mature

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th mature and immature, are determined in this component.[1] The oductive use of the reproductive condition of the herd is under .e control of the herd manager through the breeding policy that is :lected for use.

Management decision making constitutes the last component of ıis enterprise model. Because this thesis is oriented toward proiding a manager with a tool to improve his decisions, this compoent is very important. The component is constructed as an expression f the belief that optimization is not an appropriate approach for he questions that this study attempts to address. The reasons for his belief can be briefly summarized as follows: (1) the decisions :ontrolling the breeding action are highly dependent on the long time lelays before productive revenue is possible (2) herd management of :eproductive animals is highly dependent on the future prices expected, and (3) animal prices are unstable and highly volatile (especially in the recent past). The substitute for optimization of decisions is exogenous supply of control variable values. This means that whenever straightforward economic criteria cannot be explicity used to make a decision, that the management component requires an input of control values. The values used are up to the user. This technique provides an opportunity for the user to explore alternative control values based on his intuition and knowledge of the behavior of the system.

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[1]Developed by Margaret Schuette in partial fulfillment of the M. S. requirements, Department of Animal Husbandry, Michigan State University.

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This section has briefly discussed the general organization of
ie enterprise simulation model. The major processes modeled by the
ive components of the system model have been reviewed. The four
iysical components have been shown to involve cattle growth and matu-
ation, plant growth, feed value energetics, and feed crop usage. The
peration of the management component involves interaction of the user
o provide control variable values. The following section will again
iscuss each component, but in a more formal sense, setting forth the
ariables used in the mathematical model of the component. The use
f these variables in the models will be explained.

[V.2 Specific components

This section will provide a description of the content of each system component as it has been modeled. The major variables used, the physical basis for the model, and the assumptions made in developing the model will be discussed for each component model.

Cattle Demography Component

Development of the cattle demography component has been heavily influenced by the requirement that population be maintained in a way that disaggregates on the basis of sex, age, and function. This has led the model to be constructed using nine cohorts to describe the members of the herd. These are: (1) mature females, (2) replacement heifers, (3) bred heifers, (4) mature bulls, (5) young bulls, (6) steers, (7) male calves, (8) female calves, and (9) slaughter heifers. Table 4.1 provides a more detailed explanation of the exact age/sex/function disaggregation of these nine herd cohorts. The variable

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$_i(t)$ is the total population of cohort i. While this level of
ording herd population may seem quite detailed, in reality it is
nearly fine enough, as these groups do not behave homogeneously
h respect to growth and reproduction. Accordingly, further disag-
gation is provided by the variable $SUBPOP_{ij}(t)$, which records the
nber of animals in the j^{th} subpopulation of cohort i. The number
subpopulations for each cohort varies with the homogeneity pre-
sion required. For example, the replacement heifer cohort must be
scribed rather exactly, since the onset of first estrous in these
ifers is an indicator of reproductive maturity. This requires a
rger number of subpopulations than does the slaughter heifer cohort
which estrous cycling is of no interest. The variable KK_i is the
mber of subpopulations used for cohort i.

$$P_i(t) = \sum_{j=1}^{KK_i} SUBPOP_{ij}(t) \qquad (4.2.1)$$

Each subpopulation of a cohort assumes that the level of maturity
s homogeneous for that group. Age and maturity are rather highly
orrelated in the typical operation in the U. S., but some variation
oes exist. This variation leads to characterization of maturation
s a distributed parameter process. The ages of individual members of
group having the same level of maturity are distributed around a
ean. Some individuals are older than the mean, and some are younger.
he total length of time required for individuals to pass from "young"
ature cows to "old" mature cows no longer breedable is also a dis-
tributed value. Thus, for mature cows (and for all the herd cohorts),

Table 4.1 Age and Sex Description of the Cattle Herd Cohorts

Description	Cohort 1	2	3	4	5	6	7	8	9
male, 0-6 month	-	-	-	-	-	-	x	-	-
male,6-24 month	-	-	-	-	x	x	-	-	-
male, 24 month	-	-	-	x	-	-	-	-	-

(a) male animals

Description	1	2	3	4	5	6	7	8	9
female,0-6 month	-	-	-	-	-	-	-	x	-
female,6-24month	-	x	x	-	-	-	-	-	-
female, 24month	x	-	-	-	-	-	-	-	-

(b) female animals

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the delay time is a distributed parameter process. $DELAY_i(t)$ describes the average length of time for individuals to pass through the range of maturity that is represented by cohort i.

Flow rates of animals per year is a desirable way to describe the movement of animals through the various cohorts and subpopulations within cohorts. Inputs to delay processes and outputs from delay processes are easily visualized in this description. A distributed delay process may be represented mathematically by a k^{th} order differential equation:

$$a_k \frac{d^k y(t)}{dt^k} + a_{k-1} \frac{d^{k-1} y(t)}{dt^{k-1}} + \ldots + a_0 y(t) = x(t) \qquad (4.2.2)$$

where:

$x(t)$ = the input rate

$y(t)$ = the output rate

$a_1, a_2, a_3, \ldots, a_k$ = constants.

The order of the equation, k, determines the nature of the response for a particular delay time. The higher the value of k, the more tightly clustered will be the distribution of individual delay times. The value of k is a modeling parameter that is specified to most closely simulate the actual parameter distribution as recorded by experimental observation. Figure 4.2 illustrates the change in response of different values of k in a distributed delay process. Figure 4.3 illustrates, for purposes of comparison, the behavior of a discrete delay process where all individuals have a common delay time.

The variable $W_{ij}(t)$ describes the average weight of members of $SUBPOP_{ij}(t)$. Weight gain as a result of energy intake above the minimum

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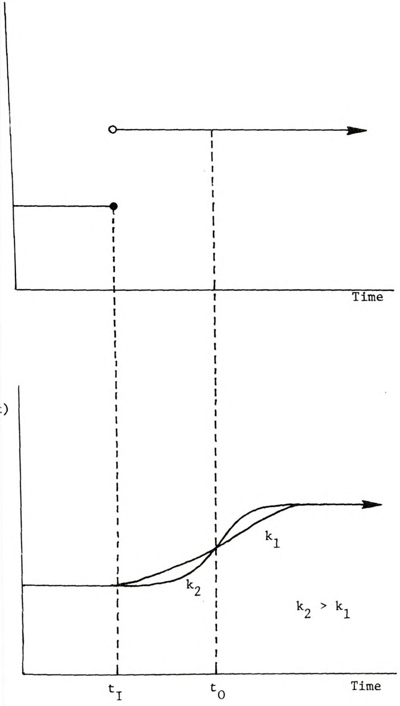
nimum metabolic requirement is represented by the variable $DGAIN_{ij}(t)$, th the subscripts again referring to the subpopulation of the herd at $SUBPOP_{ij}(t)$ counts. The average slaughter grade or slaughter ass of cattle described by $SUBPOP_{ij}(t)$ is the value of the variable ADE$_{ij}(t)$.

Births and deaths are the final processes of the demography mponent that remain. $BR_i(t)$ and $DR_i(t)$ are variables representing ese processes, respectively, on the basis of an annual rate. Only horts 1, 2, and 3 have $BR_i(t)$ values because these are the only eedable female cohorts. The simple distributed delay model of quation 4.2.2 is flow conserving; that is, all of the flow which nters the delay subsequently leaves the delay through the output ariable. This does not appear to fit the case of cattle maturation, ecause deaths and sales before final maturity are commonplace occur-nces in cattle enterprises. This problem will be solved in the evelopment of the exact mathematical equations for the maturation rocess in Chapter V.

orage Growth Component

Plant growth as a response to energy and nutrient inputs is the subject of this component model. The biological growth process is exceedingly complex. Solar radiation--SOLAR(t), average temperature--AVGTMP(t), and rainfall--RAIN(t), are the exogenous variables driving this process. The model developed here is to some extent a modifica-tion of a grasslands model developed by Parton and Marshall [40]. While much more detailed models of this growth process could be



ɡure 4.2 Graphical illustration of the response, Y(t), to an input, X(t), for a distributed delay process

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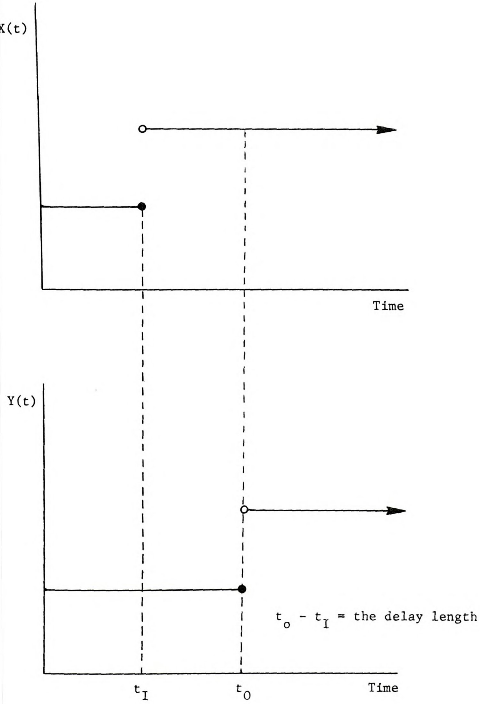

Figure 4.3 Graphical illustration of the response, Y(t), to an input, X(t), for a discrete delay process

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eloped, the present effort is felt to be adequate for the needs this thesis.

Animal consumption is the primary end use for the forage growth s model describes, whether grazed or harvested for later consump- n. Since the nutrient value of animal feed inputs is of great ortance, the digestibility, DIGEST(t), and energy value of forages included in this model. The model divides the biotic component o two materials, green plant material--GRN(t)--suitable for graz- , and root storage--ROOTS(t). Grazing is strictly limited to een material. The abiotic component consists of soil with two operties of interest; these are soil moisture, SM(t), and soil trients, SNUT(t). SNUT(t) is a composite of all of the nutrients portant to plant growth: nitrogen, phosphorus, potassium, and trace tals. SM(t) is determined as a result of three variables interact- g over time; these are rainfall--RAIN(t), percolation of soil mois- re--PERC(t), beyond the depth that roots can reach, and evaporation-- AP(t). Because grazing management is an area that will be of im- rtance to evaluation of enterprise decision-making, the model is nstructed so that different land parcels are available for varying es. The size of these parcels, $LAND_n$, is arbitrary, but it is sumed that they are each homogeneous with respect to all variables ed in this model. The subscripts n on the variables of this com- nent model refer to values for the n^{th} land parcel; NLANDS is the tal number of these land parcels.

The growth process within an individual land parcel begins with e fundamental exogenous input--SOLAR(t). Solar radiation does not affect a

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ect all green plant material equally. A major distinction is made ween those areas of the plant that are in direct sunlight and those shade. This model approximates that distinction by limiting the unt of plant material available for photosynthesis per unit area. n plant density is higher than a specified threshold, the excess treated as being photosynthetically inactive. The input of solar liation on the active plant material determines a net photosynthetic ergy conversion--PHOTO(t). The relative quality of the ambient temrature, soil moisture, and soil nutrients are used to reduce this edicted quantity whenever these conditions are less than ideal.

This net photosynthetic energy is available for growth in either two places--forage greenery or root storage. The partition of this ergy is a function of the relative proportion between greenery and ot storage which already exists. A transfer of energy from root orage to greenery takes place according to the proportion of greeny and root storage quantities. Gross greenery growth rates, $ODOT_n(t)$, and net root storage growth rates, $ROOTDT_n(t)$, for the n^{th} nd parcel are the result of the interplay between the partition of otosynthetic energy and the transfer of energy from root storage to orage greenery.

The net greenery growth rate, $dGRN_n(t)/dt$, for land parcel n is etermined from $PRODOT_n(t)$ by subtracting the amounts representing nimal and mechanical harvesting. $AHR_n(t)$ and $MHR_n(t)$ are the model ariables for these latter two activities, respectively. The actual arvest, either by cattle or machine, has a greater effect on the quantity o

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ntity of plant material than the amounts harvested indicate. Waste urs in each of these activities; therefore, a waste factor is used determine a higher (and more accurate) amount of greenery removed om the land by both mechanical harvesting and grazing means. The ste factor for grazing is modeled as a function of the stocking te within a particular land parcel; high stocking rates have higher ste factors than do medium stocking rates, which in turn have higher ste factors than do low stocking rates. The net growth rate of een plant material, $dGRN_n(t)/dt$, is integrated over the time incrent of the simulation to determine the quantity of $GRN_n(t)$ for the rrent period of time.

The final mechanism of this component model is the determination current digestibility, $DIGEST_n(t)$, of the green plant material in nd parcel n. This is computed through use of an index of the averge growing time to generate the forage existing at present. The higher is value, the longer it would take at the current growth rate to ccumulate the present quantity of greenery. The digestibility of orage is assumed to decline with age. This assumption attempts to ring to the model the age dependent shifts in the proportion of plant eaf area, stem, etc. without having to actually model forage using hese different plant parts. An additional factor affecting digestiilities is the density of green plant material per animal grazing in particular land parcel. This density is determined by dividing urrent greenery by current stocking rate times days per simulation ime increment for the entire land parcel. When high forage densiies exist then the digestibility of the forage is assumed to be unchanged

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nged from the value determined previously; however, when densities ow then the previously determined forage digestibility is reduced count for the fact that animals will be forced to eat material is included in $GRN_n(t)$, but which is of very poor quality. ge digestibility is then modeled as a function of current quantity, current growth rate, season, and the current density of forage per ing animal.

Stock Component

The main function of the feed stock component is to provide a ent value for feed stocks on hand and the TDN value of each of these stocks. This model is quite simple in comparison to the other onent models. $FSTOCK_n(t)$ is the variable used to describe the tity of feed stock n on hand at the beginning of the current time od. $FQUAL_n(t)$ gives the TDN value of feed stock n. $FSTOCK_n(t)$ ges value through sales--$CSALES_n(t)$, and purchases--$STKPUR_n(t)$, crop production--$CROP_{nl}(t)$, quantities fed to cattle--$STKFED_n(t)$, through loss from pests and waste--$STKLOS_n(t)$. Except for losses stocks, each of these variables are calculated elsewhere in the rall system model. For example, $STKFED_n(t)$ is determined in the rient impact component model as a result of the allocations of feed each cohort, and the distribution of the allocations among the sible feed stocks on hand. $STKLOS_n(t)$ is computed in the feed stock el by multiplying an annual fractional loss rate for the n^{th} feed ck, $FRCLOS_n(t)$, by the current quantity of feed stock n on hand.

The change in quality of feed stocks is highly influenced by rate of turnover of the stock itself. The variable $SPOIL_n(t)$ is used to dete

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to determine the annual rate of decline in TDN values for feed n. The particular values used are read in as data by the model in the initialization phase of the program. Each time period new average TDN value is determined by accounting for the TDN from of the following sources: carryover from the previous simulation period, new purchases, and crop production. The average amount the sum of these three sources is the value used in $FQUAL_n(t)$ for current time period.

This component handles one other minor accounting task by totaling production of crops to get annual production to date. $CROPG_n(t)$ resents the total amount of crop n harvested to this point in the vth season.

rient Impact Component

Development of this component model has been guided by the requiret to describe reproductive links with nutrient intake in considerable ail. The model uses four variables to describe the quantity and lity of the nutrient allocation for each herd cohort. $CNCAL_i(t)$ cribes the quantity of concentrates allocated to cohort i for one e period. $TDNC_i(t)$ describes the average total digestible (TDN) ue of the allocation to the ith cohort. $FEEDAL_i(t)$ describes the el of roughages allocated to the ith cohort for one time period m voluntary feeding by management. $TDNR_i(t)$ represents the TDN ue of the roughage allocation. The nutrient requirements for mals of a particular cohort for weight maintenance are predicted the basis of the animals' metabolic weights. The feed consumption of anima

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mals is predicted to be a specified fraction of their weights.
fference between the energy value of the nutrients consumed and
ergy required for weight maintenance, and other requirements, is
available for weight gain. The model uses the standard National
ch Council[2] relationships between energy and weight gain to deter-
he rate of weight gain, $DGAIN_{ij}(t)$, for the j^{th} subpopulation of
i.

Reproductive considerations in the component model are restricted
ree herd cohorts: mature cows, replacement heifers, and bred
rs. Reproductive requirements for bulls are assumed to be zero
is model. The energy requirements of mature cows vary depending
e age of the calf they are nursing, their current state in the
tion period, and their breeding status. A beef cow has certain
ological priorities which cause differential impacts if the over-
energy intake is smaller than required, and the ability to be
d is not the highest priority activity. Replacement and bred
rs come into puberty as a function of age, weight, and rate of
t gain; following puberty they have reproductive cycling just as
e cows cycle. All three of these herd cohorts have the charac-
tic that the success of breeding is a function of both current
rior feed energy intake rates.

Breeding is the major event that the model uses to bring repro-
ve dynamics into herd population dynamics. $TBRD_i$ and $DURB_i$

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[2] National Research Council, Nutrient Requirements Of Domestic
als: Number 4--Nutrient Requirements of Beef Cattle, 4th Revised
ion, 1970.

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.be the onset and duration of breeding for the i^{th} cohort. INB_{ij} ents the number of servicings for $SUBPOP_{ij}(t)$. $CTIM_{ijk}$ gives me of calving that corresponds to the k^{th} servicing of $SUBPOP_{ij}(t)$. $_{jk}$ represents the predicted accumulated calving rate after the ervicing. Figure 4.4 depicts the expected calving pattern for $P_{ij}(t)$ as a result of its breeding activity.

In Figure 4.4 the first point (subscripted ij,1) describes the rtion of cows giving birth to calves during the interval of time the beginning of the calving period to time point $CTIM_{ij,1}$. arily, the second point describes the cow proportion giving birth me point $CTIM_{ij,2}$. The final point (subscripted ij,5) describes verall proportion of cows giving birth over the entire calving n. BEGCAV(t) and ENDCAV(t) describe the beginning and ending of urrent calving season, respectively. A pattern of calving for female cohort capable of reproducing is determined by computing eighted average of the entire cohort using the number within each pulation of that cohort as the weight for the individual subpopu- n pattern. An adjustment factor, PADJST, can be used to scale the entire calving curve to reflect the incidence of disease and factors affecting breeding, if desired. The instantaneous birth at any point in time is determined for the cohort by differen- ng the cohort calving pattern.

For details concerning the model for this component one should lt Schuette[48].

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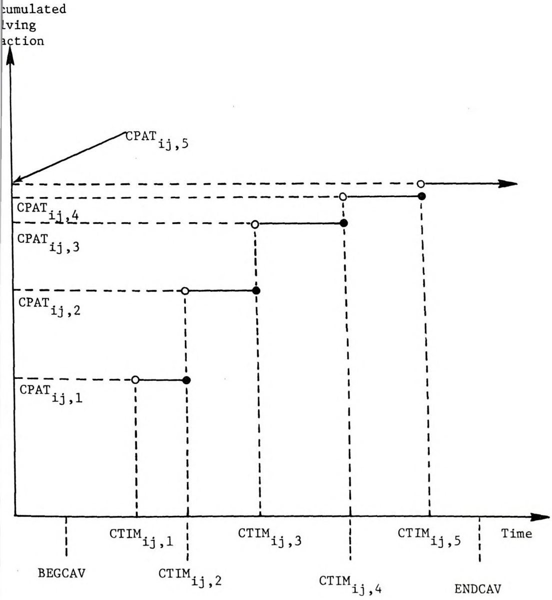

igure 4.4 The accumulated calving fraction versus time

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ıgement Decision Making Component

Management decision making is a very complex process, especially the detailed level used in this model. A factor that contributes the complexity of the decisions is the lengthy time delays of the duction process. Management must make decisions on the basis of h current and expected prices. This makes decisions of the manager hly conditional on the expected prices he has used. An additional tor is the well known volatility of agricultural prices, including tle prices. Since the expectations of the manager are apt to change iodically, the decisions he made under the previous assumptions ut future price behavior are likely to diverge from what he would under his current expectations. An additional factor is the mul- le desired goals of the manager which cannot be readily reduced to single objective function. Thus, the decision making of a beef tle enterprise manager is not well suited to optimization proce- es for these reasons.

What information is necessary for the decision maker to use as basis for his decisions? Certainly expected prices of cattle, ps, and production resources are important. The time horizon over ch these are needed is different for each type of decision. For mple, breeding is an activity based on decisions which use prices far forward in time as the likely date of sales of the resulting spring, on the order of two years. The decision of what stocking es to use in various land parcels is likely to require only a few ths of expected prices. The states of this system are a vitally ortant category of information. Current cohort populations, current

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rent feed stock levels, current quantities of forage in each land cel, and current financial conditions are examples of states of the tem which are important to decision making. The last important egory of information is expectations about future events. What p production is expected? What is the average forage production er the growing season? All of this information is needed to describe conditions under which decisions are made, whether they are made dogenously or exogenously.

This component has been developed with regard to the general quirement that the control variables of the model be able to simulate e decisions made by an actual enterprise manager operating a ranch. is has meant that very detailed control variables are needed; in neral, much more detailed than have been used in agricultural simu- tion models in the past. The major decisions that the manager must ke to control his enterprise include:

(1) timing and level of sales and purchases of cattle,

(2) timing and level of sales and purchases of feed stocks,

(3) feeding rates and types of feed for each cattle cohort,

(4) stocking rates during the forage growth season,

(5) timing and level of mechanical harvest of forage,

(6) timing and extent of breeding, culling, and weaning.

e following control variables are included in the simulation model carry out the above list of operating decisions.

(1) $ADDRT_i(t)$ = the net annual rate of additions to the i^{th} herd cohort

(2) AGEMIN = the minimum age of calves to be weaned

(3) $CSALES_n(t)$ = quantity of feed stock n sold this period

(4) $CATTIN_{im\ell}(t)$ = the quantity of TDN of feed type m fed to a member of cohort i per day during the period of the ℓth feeding plan

(5) $CNCFRC_{in}(t)$ = the fraction of the concentrate TDN allocation to be derived from feed stock n

(6) $CULFRC_{j}(t)$ = the fraction of the population of the j^{th} subpopulation of cohort 1 to be culled

(7) $DURB_{i}(t)$ = the duration of the breeding period for cohort i

(8) FPLANS (t) = the time at which the ℓ^{th} feeding plan ends

(9) $MHR_{n}(t)$ = the rate of forage harvest from land parcel n

(10) PADJST = calving rate adjustment factor

(11) $PDSTRB_{in}(t)$ = fraction of the population of cohort i that is to graze in land parcel n

(12) REMOVL(t) = fraction of the forage to be harvested

(13) $RHGFRC_{in}(t)$ = the fraction of the roughage TDN allocation to be derived from feed stock n

(14) $TBRD_{i}(t)$ = time of breeding onset for cohort i

(15) TCULL(t) = time of mature cow culling

(16) $TFRAC_{ji}(t)$ = the fraction of the weaned female calves from the jth subpopulation transferred to cohort i

(17) $TMHR_{k}(t)$ = time of the kth forage harvest

(18) TWEAN(t) = time of weaning for calves

(19) $STKPUR_{n}(t)$ = quantity of feed stock n purchased this period.

Decision making in this component model, as has been previously lained, is performed both endogenously and exogenously. When a ision can be made without recourse to exogenous input, it is so e. Such endogenous decisions include: (1) timings and quantities sales of the two slaughter cohorts--steers and heifers, (2) the ision to harvest forage as guided by preseason planning, (3) sales purchases of feed stocks to obtain the winter feed base, and

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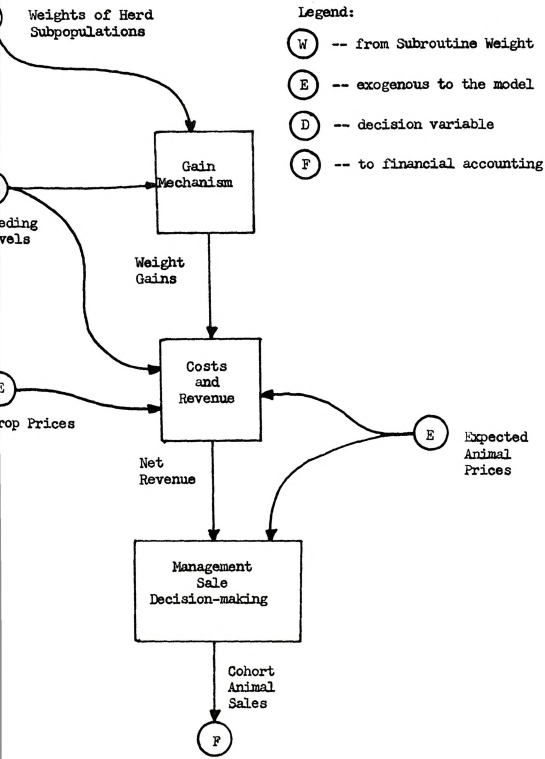
the actual feed allocations of concentrates and roughages fed to herd as guided by the feeding plans and adjusted to meet forage ntity problems as well as feed stock shortages. Figures 4.5 through indicate the decision mechanisms and the variables used in each the four endogenous decisions.

The remaining herd decisions are determined by the user by input- ng control variable values exogenously. These decisions include:) determining stocking rates for herd cohorts, (2) breeding activ- y which includes timing, duration, and type, (3) weaning of the calf horts, (4) sales from or additions to the herd cohorts, (5) movement animals through the cohort structure following maturation beyond s former range, and (6) culling of the mature cows. Four of these ypes of decisions are clearly associated with particular physical vents; these are the onset of spring forage growth, breeding, culling, nd weaning. The component model has been developed so that these our events, termed "decision points", are recognized and control var- ables are sought upon recognition. A fifth "decision point" also alls for exogenous input of control variable values when any of three vents occurs; these are (1) the quantity of feed stocks is less than he current rate of feeding times two periods, (2) working capital alling below $2000, and (3) the quantity of feed stocks at the end of he growth season being significantly different from the feed require- ents for the wintering season. Figure 4.9 is a blow up of Figure 4.1 hich shows the mechanism whereby the management decision making omponent recognizes that a decision point exists and acts to achieve he needed input of control variable values by the model user.



'igure 4.5 Decision mechanism for slaughter cohort sales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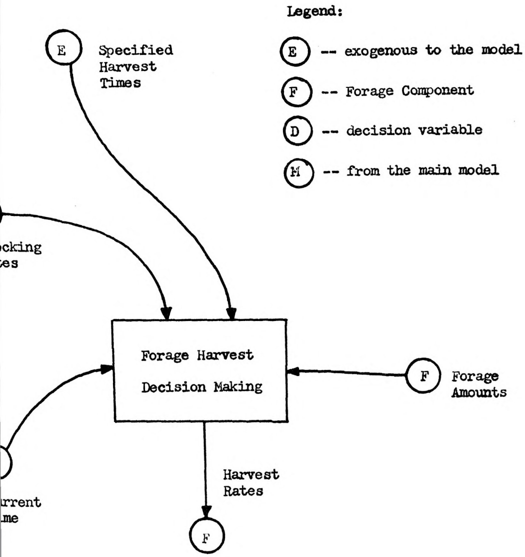

igure 4.6 Decision mechanism for forage harvesting

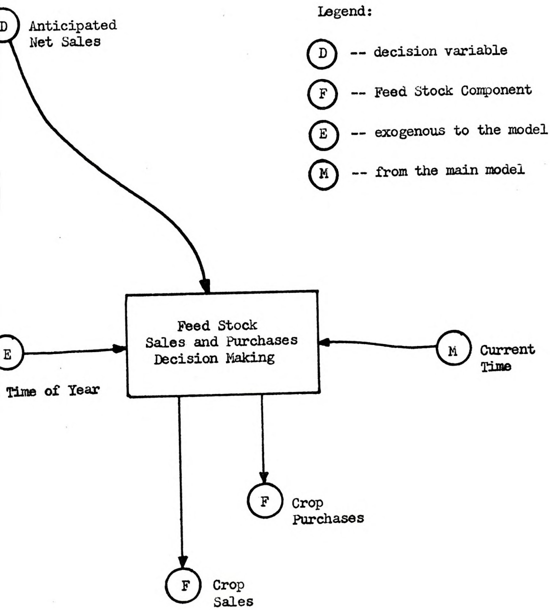

Figure 4.7 Decision mechanism for feed stock sales and purchases to obtain wintering nutrient requirement

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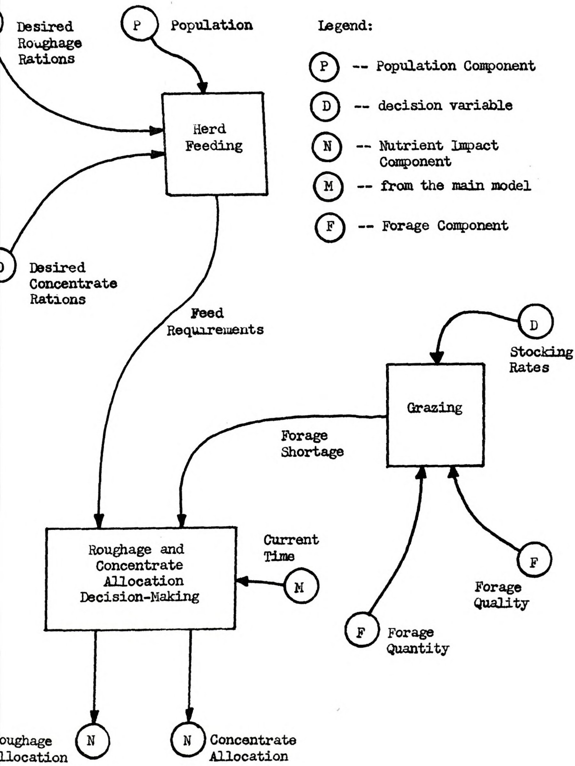
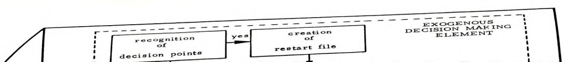


igure 4.8 Decision mechanism for herd feeding allocations



EXOGENOUS DECISION MAKING ELEMENT
recognition of decision points
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creation of restart file

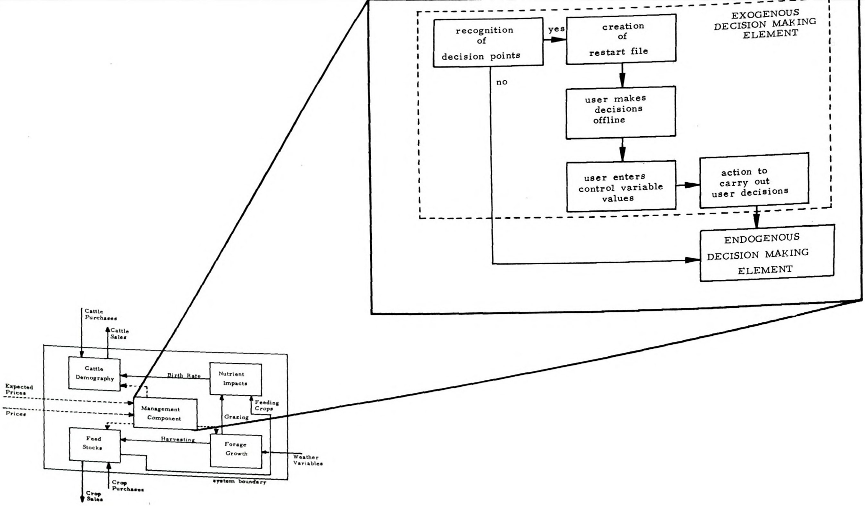

Figure 4.9 Blowup of the general system diagram to show functional details of the management decision making component

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Figure 4.9 illustrates the operation of the management decision king component with the two elements--exogenous and endogenous ecision making--logically related. The component constantly checks o see if any condition requires the use of exogenous control variable alues from the model user; if none is required, then logical control asses to the endogenous decision making element. When an event or ondition does trigger recognition of a decision point, then the steps hown in the exogenous decision making element are followed. The model simulation is stopped after current state variable information is printed; this pause allows the user to study the current situation at his leisure and input control variable values to implement his resulting decisions. The model is restarted from the exact point at which it stopped and continues the simulation as before, except that the controlling actions of the user are substituted for any previous control decisions or decision making criteria. This sequence of events is followed in every time increment of the time simulation to insure that decision points requiring human decision making are recognized when they exist.

Secondary System Components

In order to simulate the beef cattle enterprise in the way that the problem statement requires, several secondary components are also needed. A component performs the task if determining the proper value of the exogenous variables--crop production, prices, and weather--for he current time. The main program reads in as data an entire year f exogenous variable values in its initialization phase; a subroutine is called

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s called at the beginning of each time iteration which determines he appropriate exogenous values to use.

The financial effects of alternative policies are the most important outputs to use in choosing among the policies. This requires that a financial component be included that accounts for the monetary effects of sales, purchases, and payments. This information is used in two different ways. First, the ongoing management process requires information about present, immediate past, and current values of such variables as yearly net profit to date. Second, when the final time horizon of the simulation has been reached, the user wants summary information to help him to analyze and interpret what has occurred during the simulation. These tasks are carried out by a package of subroutines which perform all necessary financial accounting and analysis.

The last secondary component is one which manages the expected prices that the manager uses as the basis for his decision making. In the initial program start and at each decision point, the future stream of expected prices for cattle and crops changes. This component reads in this new information as needed. A second task is to adjust the future expectations to account for the passage of time. As simulated time is incremented forward, this component shifts the future expectations toward the present and records the most recent past value in the pst expectations variable. It gives the decision maker the opportunity to know what price he expected to encounter at times that have come and gone.

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.3 Simulation Model Operation

Operation of this simulation model is heavily influenced by the teractive management component. Initially, the user reads in the iitial conditions and system parameters for the particular enter-rise to be studied. The model will automatically simulate the nterprise behavior through time until a decision point is reached. t this point the model requires the user to input specific values or particular control variables. These values implement the deci-ions that the user has made. The model then continues its simula-ion through time until the next decision point is reached. The rocedure is repeated until the final time horizon of the simulation run has been reached. Figure 4.10 illustrates the organization of the management component and its relation to the other system components in the simulation loop.

When the management component detects that a decision point has been reached, a detailed printout of the current status of the enter-prise is made. This printout typically includes the current herd subpopulation breakdown, current feed stock quantities, the expected cattle and crop prices over a future time horizon, and current finan-cial status. The user must carefully study this information to make his decision about what is to be done at this point in time. The user may be investigating the effects of a particualr decision rule; he would input control variable values to follow that decision rule. The user also inputs new expectations about future prices and events.

At the time that the management component completes printing of he decision assistance information, it prints all variable values

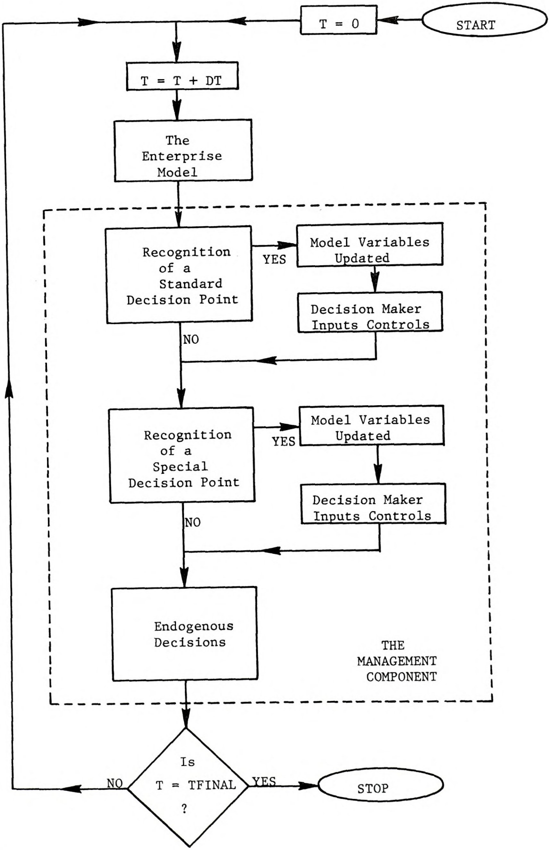

Figure 4.10 Flow diagram of the management decision making component in relation to the simulation model

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into a permanent file in the computer. This file enables the model to be restarted at exactly the same point and under the same conditions as when it stopped. When the user restarts the model after making his choice of decision variable values, the first action is to read from the permanent file to reestablish all model variables with the proper value, the second step is to read the control variables (using the formats given in the User's Guide to the Beef Cattle Enterprise Simulation Model), and finally to implement these values to control the enterprise simulation model. An extremely valuable characteristic of this interactive management component is the ability to return to a decision point that has already been passed by, input new control variable values, and continue the simulation from that point. At each decision point any number of control variable sets can be used by restarting the model with the desired control values, proceeding to the next decision point, printing all values into a permanent file, and returning to the original decision point. Figure 4.11 illustrates the decision tree of alternative control sets that can be evaluated. The key to this ability is the permanent file that is created to "freeze" the simulation as it was at a decision point. As long as the user does not dispose of these permanent files, he retains the option of returning to any one and proceeding forward in time with any control values that are desired.

This evaluation of alternative strategies method of use will be employed later in this thesis to explore some management strategies for (1) age of weaning, (2) rate of herd development projects, and (3) general profit maximization.

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Use of the Simulation Model

The simulation model is a tool for the user to employ in evaluating specific alternatives confronting his own operation. Certain activities, such as breeding, weaning, etc., are highly complex decision and quite dependent on future prices and events. When the user approaches such events in real time, he wants to begin to evaluate his possible courses of action. He would then start up the model with the current states of his cattle herd, forage in the field, feed stocks on hand, expected crop production, financial condition, etc. In effect, he initializes the simulation model to correspond to the states of his own enterprise. Then the model is used to explore the future consequences of his decision options through simulated time. After having explored the alternatives using the simulation model, the decision maker is in a much better position to make his real world decisions. At any time that conditions in the real world deviate from the user's previous expectations, he can use the model to investigate the effect of these differences on his enterprise. Revision of previously made decisions is possible on the basis of the results of these investigations. The user of the model is alerted to real time events that require investigation through use of the simulation model by his own awareness of weather, prices, political events, etc. The simulation model is an assist to the manager of a beef cattle enterprise, not a substitution for the experience and intuition of the manager.

The simulation model has simulated the dynamics of the enterprise through time but in ways that are not completely accurate. Two

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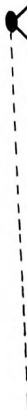

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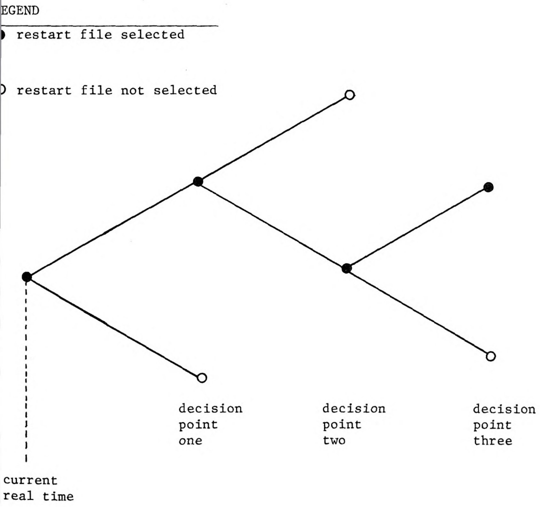

Figure 4.11 "Decision Tree" of alternative strategies investigated using the simulation model's restart capability

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sources of inaccuracy provide the bulk of the reason for the divergence between real and simulated values. The first of these is inaccuracy in the simulation model formulation itself; this is due to modeling errors and approximations that simulation makes to develop a solution to the mathematical model of the enterprise. The second source of inaccuracy is management decisions in the real world system that do not conform to those made in the simulation. For these and other reasons, the simulated enterprise behavior will never follow exactly the same path as the behavior of the real world enterprise. At each point in real time requiring alternative decision explorations, the model should be reinitialized with the current states of the model variables used to describe the enterprise. The simulation model has been constructed so as to be available for use by an enterprise manager at any time and to be as flexible as possible to accommodate his needs.

IV.4 Summary

This chapter has provided a general description of the simulation model that this thesis has developed. Five major and three secondary components of the model have been reviewed. The operation of the model by the user has been discussed. In the aggregate these components constitute the model that will be used to investigate strategies of management decision making by this author and other users. Figure 4.12 provides an overview of the major components and the key control points that provide the means of implementing the decisions made endogenously by the management algorithm and exogenously by the user. Figure

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user. Figure 4.13 provides a pictorial description of the calling sequence of the model as it simulates the system over a desired time horizon. The following chapter will present the detailed mathematical equations that form the mathematical models that are simulated in the computer programs.

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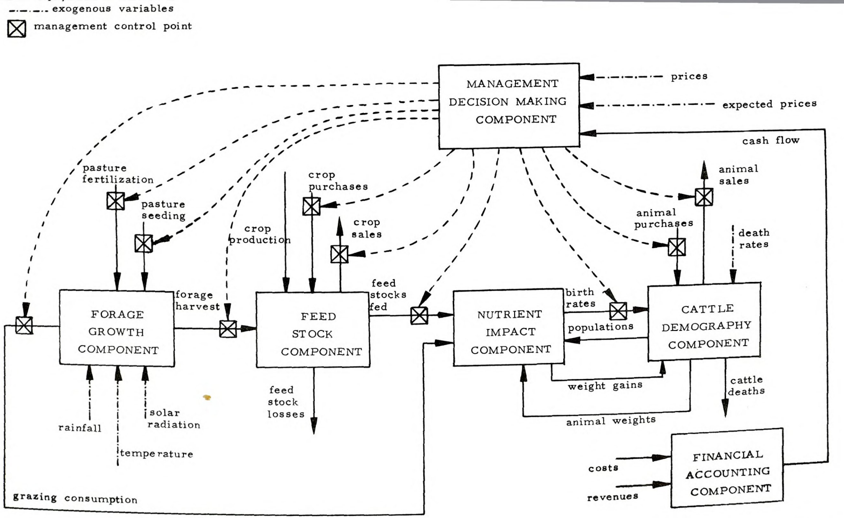

Figure 4.12 Enterprise system diagram illustrating physical and information flows between components

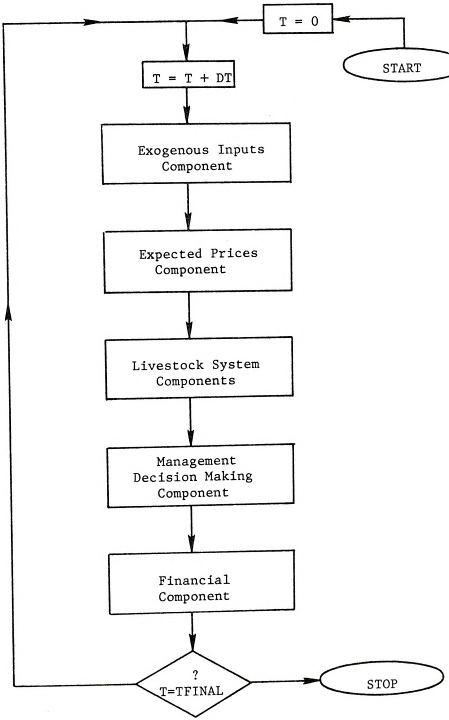

Figure 4.13 Calling sequence of the simulation model components to simulate the beef cattle enterprise through time

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CHAPTER V

DETAILED MODEL DESCRIPTION

This chapter will build upon the general description of the model ;ented in Chapter IV. This chapter will take the variables defined :he previous chapter and develop the mathematical equations which the basis for the computer subroutines of the simulation model. ı of the five major system components will be discussed as a arate section; the secondary components will constitute another tion, and the final section will summarize the enterprise model.

A complete listing of the computer program and its subroutines can found in User's Guide to the Beef Cattle Enterprise Model, a separate ume from this thesis. Complete instructions for operating the model m either the initialization or restart mode may be found in this ume as well.

Cattle Demography Component

This component model uses four subroutines to provide the sim- tion of the birth, death, and maturation processes. Subroutine HDMOG4 the major element; it maintains herd populations on a disaggregated is by age, sex, and function. Subroutine WEIGHT determines the rage weight of particular subpopulations as the herd matures and s. Subroutine BIRTH2 computes an instantaneous birth rate as a ction of prior nutritional status and breeding activity. Subroutine AT is used by BIRTH2 to determine birth rates by combining the dicted birth information about each female subpopulation into birth es that apply to an entire cohort population.

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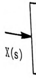

Figu

The key to the model of maturation is recognition that
ration is a process in which age is a distributed parameter.
tion 4.2.2 provides the basis for the model of this process, but
oes not allow for cases in which flow is not conserved. Flow is
conserved in the maturation process because of deaths, sales,
additions to the herd. These occur throughout the range of age
red by the cohort delay. Following Manetsch [38] one applies
Laplace Transform to 4.2.2 to obtain

$$Y(s) \prod_{i=1}^{k} (D_i s + 1) = X(s) \qquad (5.1.1)$$

where:

$Y(s)$ = transform of the output time function

$X(s)$ = transform of the input time function

solving for $Y(s)$, one obtains

$$Y(s) = \prod_{i=1}^{k} \frac{1}{D_i s + 1} X(s) \qquad (5.1.2)$$

form suggests that the kth order distributed delay can be modeled
1st order delays in a cascaded form. Figure 5.1 illustrates this
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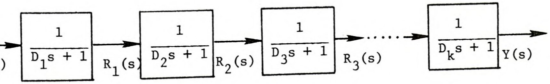

gure 5.1 Decomposition of a kth order distributed delay into a series of k first order delays

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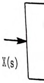

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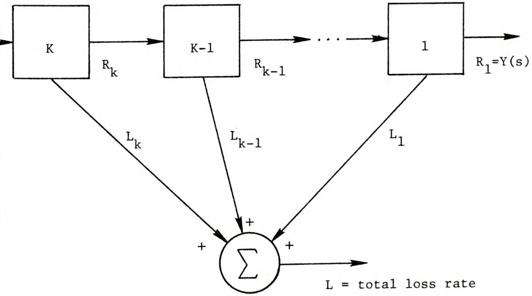
of the individual first order delays of Figure 5.1 are referred tages within the overall delay.

Since flow is not conserved in the case of maturation, there loss from the delay. In general there can be a loss from each he stages of Figure 5.1, which in the aggregate sum to the total from the entire delay. Figure 5.2 illustrates this idea of es from individual stages. Notice that the numbering of the es has been reversed in this figure to conform with the usual ention [32, 38].



gure 5.2 Kth order distributed delay with losses

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any moment the total number of individuals in the ith stage (the orage in stage i), $Q_i(t)$, is a function of the flow rate, $R_i(t)$, and e length of the ith delay, $D_i(t)$. This gives

$$(t) = D_i(t)*R_i(t) \tag{5.1.3}$$

the total delay for the entire process, D(t), is spread uniformly er all k stages, then 5.1.3 becomes

$$_i(t) = \frac{D(t)}{K}*R_i(t). \tag{5.1.3a}$$

osses from this quantity can be individually specified, but as a implyfying assumption, let a common proportional loss rate, PLR(t), pply to all stages. Then the loss, $L_i(t)$, is

$$_i(t) = PLR(t)*Q_i(t). \tag{5.1.4}$$

he net change in storage for the ith stage follows the following ifferential equation,

$$\frac{Q_i(t)}{dt} = R_{i+1}(t) - R_i(t) - L_i(t) \tag{5.1.5}$$

ecause the rate of change in the quantity is the rate of input to the elay minus the rate of output. Referring to Figure 5.2 gives the nput rate to state i as $R_{i+1}(t)$, while the output rate is the sum of he output going to the next stage, $R_i(t)$, and the loss, $L_i(t)$. ifferentiating 5.1.3 gives

$$\frac{Q_i(t)}{dt} = \frac{D(t)*dR_i(t)}{Kdt} + \frac{R_i(t)*dD(t)}{Kdt} \tag{5.1.5a}$$

quating the right hand sides of 5.1.5 and 5.1.5a and solving for $R_i(t)/dt$ gives the following,

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$$\frac{dR_i(t)}{dt} = \frac{K}{D(t)}\left\{R_{i+1}(t) - R_i(t)\left[1 + \frac{D(t)*PLR(t)}{K} + \frac{dD(t)}{Kdt}\right]\right\} \qquad (5.1.6)$$

This is the general expression for the ith stage of a kth order distributed delay with proportional loss rates and a time varying delay length.

Subroutine DLVDPL is used to simulate a delay process which follows equation 5.1.6. $RIN_{ij}(t)$ represents the jth stage flow rate for the ith herd cohort. The storage for that stage, $SUBPOP_{ij}(t)$, is determined by equation 5.1.3a using the cohort delay length, $DELAY_i(t)$, and the number of stages in cohort i, namely KK_i. Then

$$SUBPOP_{ij}(t) = \frac{DELAY_i(t)*RIN_{ij}(t)}{KK_i} \qquad (5.1.7)$$

The total storage of the ith delay process (cohort i) is simply the summation of the storage in each stage. This gives the total cohort population as

$$POP_i(t) = \sum_{j=1}^{KK_i} SUBPOP_{ij}(t) \qquad (5.1.8)$$

A distributed delay is an excellent way of modeling the physical process of maturation. For some purposes, the actual age and weight may serve better. this is the case for prediction of the oneset of puberty in heifer calves. What is needed is a delay model that is not distributed; the output rate is a uniform delay of a prior input rate. When proportional losses and the potential for a time-varying delay length are required, the delay process becomes more complicated than the simple illustration of Figure 4.3.

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) = X(t - d) (5.1.9)

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Y(t) = output rate at time t

X(t) = input rate at time t

d = the time delay

the time delay, d, is an integer number of DT time increments, then

) = X(t - N*DT) (5.1.9a)

ice that this process can also be represented in terms of a cascade single stage delays, with each stage corresponding to a delay of DT. Then,

:) = R_1(t - DT)

:t) = R_2(t - DT)

$_{-1}$(t) = [1 - PLR(t)]*R_N(t - DT) = X(t) (5.1.11)

en the delay length, d, changes, then the number of stages separating e input and output must change correspondingly, because the delay ngth for each stage is fixed as DT. If the delay length increases, en there will be an interval with no output rate until the extra mber of required stages of DT delay are completed. If the delay ngth is decreased, then a large output rate will suddenly occur as e storage of the excess number of stages leaves the delay model.

Subroutine DVDPLR has been developed to simulate this form of screte delay with proportional losses and variable delay time.

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rage in this discrete delay is computed in the same way as equation .7 computes storage for a distributed delay. Since each stage responds to a fixed delay of length DT,

$$POP_{ij}(t) = DT*RIN_{ij}(t) \qquad (5.1.12)$$

For this simulation model cohorts 1, 4, 5, 6, and 9 are modeled ng distributed delays and cohorts 2, 3, 7, and 8 are modeled using crete delays.

The proportional loss rate, $PLR_i(t)$, that applies to the i^{th} ort is made up of two loss factors. These are the death rate, (t), and the net rate of annual additions to the cohort, $ADDRT_i(t)$. ce this variable is not on a proportional basis as is $DR_i(t)$, it divided by the current population of the cohort to obtain

$$R_i(t) = DR_i(t) - \frac{ADDRT_i(t)}{POP_i(t)} \qquad (5.1.13)$$

is loss rate is on an annual basis; therefore, within the delay routines, the loss rate that applies for a single incremental me period is $PLR_i(t)*DT$. If $POP_i(t)$ is zero and $ADDRT_i(t)$ is sitive, a special mechanism adjusts the populations to reflect an dition of animals through the $ADDRT_i(t)$ control variable. $DR_i(t)$ r each of the nine herd cohorts is read into the model as data in e initialization phase of the main program. It is assumed constant er the entire length of the simulation. An improvement that could made in the model would be to internalize some part of the death te as a function of the weather variables, to simulate exposure, d as a function of the nutrient intake over time, to simulate weakenin

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ening from poor nutrition. Since the death rates are actually tant, a more proper designation is DR_i. $ADDRT_i(t)$ is a control able that the user can specify as desired at any of the decision its which call for that as a variable for exogenous control. (t) is used in the cohort delay models as explained above.

To reiterate, each of the nine cohorts of the cattle herd is resented by a delay process, either subroutine DVDPLR or soubroutine DPL. The output flow rate from the i^{th} delay, $ROUT_i(t)$, represents annual flow rate of animals from that cohort at time t. What pens to these animals? For example, what happens to female calves they age beyond the delay length given by $DELAY_8(t)$? Presumably delay length is set to represent a natural weaning age which acts wean all calves which get to that age and still have not been ned. These weaned calves can be handled in a number of alternative s: (1) entered into the replacement heifer cohort, (2) entered o the bred heifer cohort, (3) entered into the slaughter heifer ort, or (4) sold on the market as weaned calves. Management must ide what fraction of these calves are used for each of the above r uses. Three control variables act to carry out the manager's ision; these are C3, C5, and C9. In a similar fashion the manager st decide how the output from each of the nine herd cohorts will be ed. Figure 5.3 is a block diagram of subroutine HDMOG4; in it are ustrated the possible flows among herd cohorts, the control vari- les which direct those flows, and the general structure of the mographic model.


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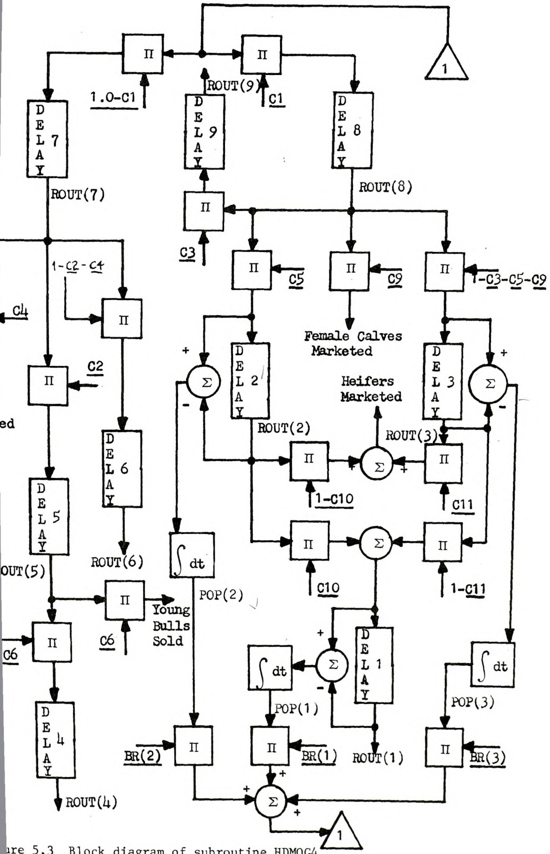

ure 5.3 Block diagram of subroutine HDMOG4

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Birth is the remaining process that this component model includes.
:hs are generated in HDMOG4 by multiplying an annual birth rate, (t), by the reproductive population, $RPOP_i(t)$, for each of the three ale reproductive cohorts--mature cows, replacement heifers, and bred Eers. Total births, CALVES, is an annual input rate which must be it between male and female calves.

$$VES = \sum_{i=1}^{3} BR_i(t)*RPOP_i(t) \qquad (5.1.14)$$

denotes the proportion of births which are female, and 1.0 - C1 the proportion which are male. The birth rate on an annual basis the reproductive population in the three female reproducing cohorts determined in subroutine BIRTH2. The major function of subroutine TH2 is to determine the value of $BR_i(t)$ and $RPOP_i(t)$ at time t. $P_i(t)$ is similar in definition to $POP_i(t)$ but is used ot maintain istinction between heifers giving birth to their first calf and ure cows who have calved at least once previously. This distinc- n is not properly developed by the $POP_i(t)$ variable because some fers in the reporduceable cohorts (numbers 2 and 3) leave those orts and enter the mature cow cohort before the calving interval been completed. Since the birth rate for the mature cow cohort based on a population of mature cows, a distinction must be drawn ween the two types of members residing in $POP_1(t)$. $RPOP_1(t)$ is actual number of mature cows in $POP_1(t)$ which have calved pre- usly. $RPOP_2(t)$ includes all members of cohort 2 which are preg- t and all former members now in cohort 1. $RPOP_3(t)$ includes all bers of cohort 3 which are pregnant and all former members now cohort 1.

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The variables BEGCAV and ENDCAV mark the beginning and the ιding of the calving interval. These are determined as a result f the previous breeding activity (roughly nine months in the past). ıen t is within the interval (BEGCAV, ENDCAV) values of $BR_i(t)$ and $OP_i(t)$ are usually non-zero, outside of this interval they are ɔth zero.

Subroutine BIRTH2 computes the birth rate for each breedable ɔhort by determining the derivative of the curve of accumulated irths over the time interval of calving. The points which make up ıis curve, $BFRAC_{il}$, l = 1, ..., INTCAV, are determined in subroutine irat using the previous breeding activity. Figure 5.4 illustrates ɔw the birth rate is numerically approximated from the accumulated irth curve for cohort 1.

Subroutine IBRAT is called at the beginning of the calving season ɔ establish the values for $BFRAC_{il}$. Three variables provide a record f the breeding history for each of the subpopulations of the repro- ιcing cohorts. INB_{ij} is the number of servicings for $SUBPOP_{ij}$ over ıe breeding interval. $CTIM_{ijm}$ is the expected calving date for $UBPOP_{ij}(t)$ which results from the m^{th} servicing; this time is the ummation of the actual time of breeding and the average gestation eriod. $CPAT_{ijm}$ is the accumulated fraction pregnant for $SUBPOP_{ij}(t)$ fter the m^{th} servicing. The $BFRAC_{il}$ curve for a cohort is determined y these variables. The number of data points composing the $BFRAC_{il}$ urve is

$$NTCAV = \frac{ENDCAV - BEGCAV}{0.025} \qquad (5.1.15)$$


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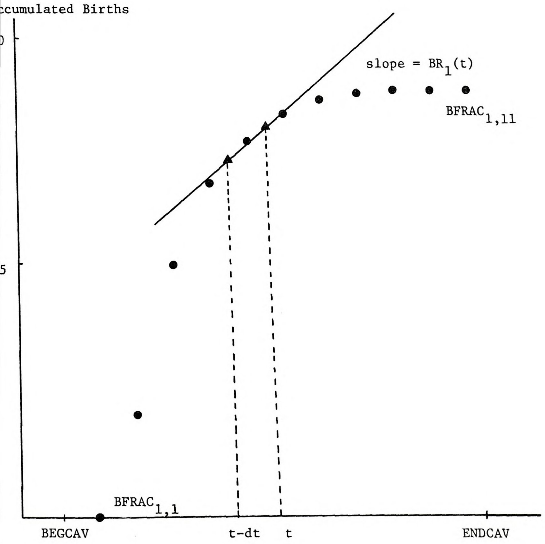

igure 5.4 Determination of the annualized birth rate by numerical approximation of the deriviative of the accumulated births curve

Figure 5.5

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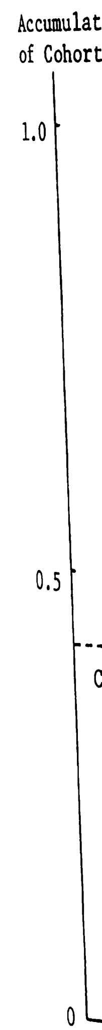
re 5.5 illustrates the way in which the predicted calving variables each cohort subpopulation are used by subroutine BIRAT to determine accumulated calving curve for the entire cohort. For ease of illus- ion, only three subpopulations will be used whereas in a typical lation model run there are apt to be 5-10 subpopulations that have bred in each of the female cohorts. Again for ease of illustra- , assume that the number of animals in each subpopulation is equal. cohort average in Figure 5.5 is then simply the average of the $_{ijk}$ values for the three subpopulations without needing to be hted by the numbers of animals in each of the subpopulations.

Cattle weights are determined through use of subroutine WEIGHT. ssumption, all animals represented by a particular cohort subpop- ion have the same weight. This value is, loosely speaking, an age weight of a fairly homogeneous group, but the value is not rmined by actually averaging individual animal weights. Weights ge in the cattle herd through two distinct but related processes; e are growth and aging. Within an individual subpopulation growth rs as a result of feed intake energy being in excess of maintenance gy requirements. Due to the passage of time, however, individuals between adjacent herd subpopulations, and even between herd cohorts. he animal that has just arrived in a subpopulation does not have same weight as the average of the subpopulation prior to its arrival the average must be recomputed to reflect its arrival. Animals ot continue to gain weight indefinitely; to account for this fact model has a constraint on weight for each herd cohort. The final ect of this submodel is price gradation of beef cattle. Fixed es have been assigned to each herd cohort. These remain constant



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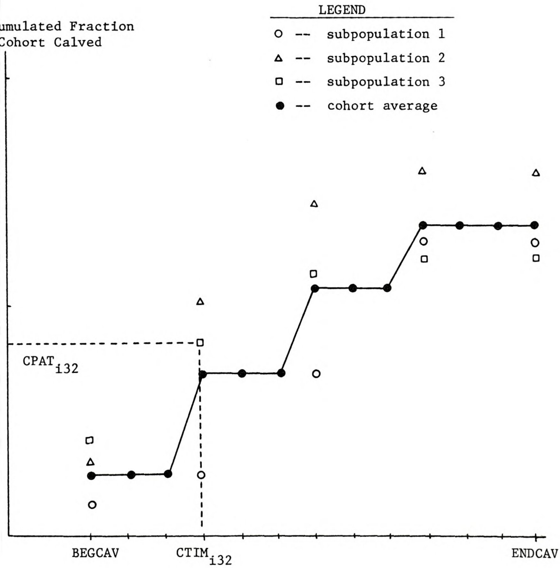

gure 5.5 Determination of $BFRAC_{il}$ values from the breeding history of each cohort subpopulation

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ss the maximum weight constraint is reached and the projected y gains would force weights higher yet but for the constraint. the excess of energy that has been directed to weight gains is rted to changing the price gradation of the cattle in that subpopion. This mechanism is assumed to reflect the changing muscle/fat ortions that exist in cattle as weight increases and which are ected in changing prices for different levels of fat in meat.

The variable $W_{ij}(t)$ represents the average weight of all animals he jth subpopulation of cohort i,i.e., those animals whose number JBPOP$_{ij}$(t). The daily rate of weight gain for animals within this opulation is $DGAIN_{ij}(t)$. If no aging (the maturation process dised earlier) were to take place, then weights would change over according to

$$t) = W_{ij}(t-dt) + \int_{t-dt}^{t} DGAIN_{ij}(u)du \qquad (5.1.16)$$

nimals aged, but did not change weight from changes in size, then average weight of a subpopulation would be solely a function of the sfer of animals between herd subpopulations. $ALPHA_i(t)$ is a measure he fraction of the animals in a subpopulation of cohort i that leave subpopulation in a single time increment.

$$A_i(t) = \frac{DT*KK_i}{DELAY_i(t)} \qquad (5.1.17)$$

e:

$DELAY_i(t)$ = the delay time of the ith herd cohort

KK_i = the total number of subpopulations in the ith cohort

DT = the length of time of a simulation time increment.

ce that $ALPHA_i(t)$ is bounded between zero and one. Because the

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and $DELAY_i(t)$ variables are constant over all subpopulations of a icular herd cohort, $ALPHA_i(t)$ is also uniform over all subpopulations hat cohort. $BETA_{ij}(t)$ is the fraction of animals in subpopulation cohort i that were in the same subpopulation in the previous time ement; therefore an approximation to the true $BETA_{ij}(t)$ value is n by

$$_{ij}(t) = \frac{SUBPOP_{ij}(t)*(1 - ALPHA_i(t))}{C} \qquad (5.1.18)$$

e:

$$C = SUBPOP_{ij}(t)*(1 - ALPHA_i(t)) + SUBPOP_{i,j-1}(t)*ALPHA_i(t).$$

approximation allows the simple form of equation 5.1.16 to be ied to each of the two sources of animals in subpopulation j; ly animals from subpopulation j and subpopulation j-1. Therefore equation for the weight of members of subpopulation j of cohort weighted sum of the weights and rates of weight gain from both of e sources.

$$t) = BETA_{ij}(t)*\left(W_{ij}(t-dt) + \int_{t-dt}^{t} DGAIN_{ij}(\tau)d\tau \right) \qquad (5.1.19)$$

$$+ (1 - BETA_{ij}(t))*\left(W_{i,j-1}(t-dt) + \int_{t-dt}^{t} DGAIN_{i,j-1}(\tau)d\tau \right)$$

tion 5.1.19 applies to all subpopulations of cohort i except the gest; the youngest is different because it involves animals transed between cohorts. The weight of the youngest subpopulation of cohort,e.g. $W_{i1}(t)$, is determined from the weight of the previous ers of that subpopulation and the weight of the animals transferred it from another cohort. An example of this transfer between rts is the movement of heifers into the mature cow cohort. The cohorts use a fixed birth weight for male calves, and another fixed

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weight for female calves. An improvement to the model would be ke these birth weights a function of the nutrient intake of the ohort through time, especially during gestation.

Weight constraints for each herd cohort are imposed by the varia- $GTMAX_i(t)$. The rate of weight gain determined in the nutrient t component is checked to see how it affects the weight of the subpopulations. This check results in the following redefinition e rate of daily gains based on the values obtained from NUTRN.

$$
{}_{ij}(t) = \begin{cases} DGAIN_{ij}(t), & \\ \quad \text{if } W_{ij}(t-dt) + \int_{t-dt}^{t} DGAIN_{ij}(\tau)d\tau < WGTMAX_i & \\ 0, & \\ \quad \text{if } W_{ij}(t-dt) = WGTMAX_i & \\ FRAC*DGAIN_{ij}(t), & \\ \quad \text{if } W_{ij}(t-dt) < WGTMAX_i, & \\ \quad \text{and } W_{ij}(t-dt) + \int_{t-dt}^{t} DGAIN_{ij}(\tau)d\tau > WGTMAX_i & \end{cases} \tag{5.1.20}
$$

:

$$
FRAC = \frac{WGTMAX_i - W_{ij}(t-dt)}{\int_{t-dt}^{t} DGAIN_{ij}(\tau)d\tau} . \tag{5.1.21}
$$

Grading of beef cattle is a complicated procedure that heavily ves subjective gradations of differences by human beings. Many of bjective measures used, moreover, are such cattle descriptors as size, height, etc. Since the gradation process and the objective s on which it is based are missing from this model the determina- of grades will quite arbitrary. An attempt will be made to relate es in grade from those initial values entered as data by the user to oc

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asions when the projected rate of weight gain conflicts with ximum weight constraint. Individual price grades are specified ch subpopulation of each cohort, i.e., $GRADE_{ij}(t)$. There are iscrete steps of grades and associated with each of them is a te cattle price; this price structure is the reason for the or cattle grading. Over the entire five grades there might be e difference of 100%. Grades are determined as follows,

$$
{}_{ij}(t) = \begin{cases} GRADE_{ij}(t-dt) + \int_{t-dt}^{t} DGAIN_{ij}(\tau)d\tau * FATFAC, \\ \qquad \text{if } W_{ij}(t-dt) = WGTMAX_i \\ GRADE_{ij}(t-dt), \\ \qquad \text{if } W_{ij}(t-dt) < WGTMAX_i \end{cases} \qquad (5.1.22)
$$

:

FATFAC = a parameter relating predicted rates of weight gains at maximum allowed weight to changes in price grade through the mechanism of muscle/fat proportions

$GRADE_{ij}(t)$ = an integer value (from 1 to 5) indicating the proper price grade characterizing any animals in the jth subpopulation of cohort i; highest prices are for grade 1, and lowest prices for grade 5.

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orage Growth Component

he grazing process is a complicating factor in the already cult problem of modeling plant growth. The interaction of cattle ants is not yet well understood. Cattle have preferences for in species of forages over others, but these preferences are dynamic e composition and digestibility of each plant species change over rowing season. To fully explore the dynamics of the grazing process el must include the following factors:

(1) growth and maturation of individual species as determined by exogenous weather variables and field conditions of canopy height, competition, slope, soil type, etc.

(2) digestibilities and consumption preferences for the major plant components--stem, leaf, new shoots, and seed

(3) impact of grazing on growth, regrowth, reproduction, and regeneration of plant species.

ly the above task is beyond the scope of this thesis. The model oped to meet the requirements of the forage growth component, as d in the problem statement section of Chapter III, is only an al step on the road toward a complete grazing model.

The growth model developed for this thesis is an adaptation of sslands model of Parton and Marshall[40]. Net photosynthetic y conversion to plant material is a product of a transfer coef- nt per unit of material times the amount of effective material the level of incoming solar radiation times the minimum of three h quality condition indices. These indices measure the relative ty of temperature, soil moisture, and soil nutrients in terms of opt

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imal growth conditions. The net growth predicted by the basic energy
nversion equation is partitioned into growth of greenery and increases
root storage by a function of the prior quantities of these values.

The amount of plant material that can effectively convert solar diation to plant growth is limited due to shading. This constraint approximated by imposing a plant density limit on the quantity of ant greenery per unit area which can convert solar radiation. Figure 6 illustrates the determination of the photosynthetically active ount of plant greenery, $ACTIVE_n(t)$, per unit area.

Three quality indices are used to describe the relative quality factors of plant growth other than solar radiation. The factors are mperature, soil moisture, and soil nutrients. The index variables scribing these are TPF(t), SMF(t), and $SNF_n(t)$, respectively. Use of ese indices implies the assumption that certain levels of these vari-les are better for plant growth than others, regardless of the level solar radiation. Figures 5.7 through 5.9 illustrate the relationship tween each of these variables and its corresponding index value. The ta points for each of the four figures, 5.6-5.9, are derived from rton and Marshall[40] and Sauer[47]. Better values could be determined rough experimental study of weather conditions and plant growth at a rticular enterprise location. The values of the three quality indices e determined by use of the table interpolation function TABLIE[32]. e value of the variable is the argument and the index value is the sult of the interpolation between data points.

The net growth rate of total plant material in any land parcel, $IOTO_n(t)$, is determined through the following equation, ACTIV

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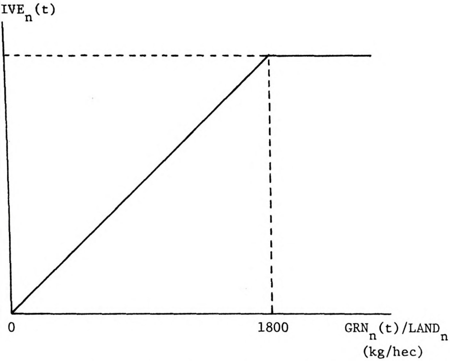
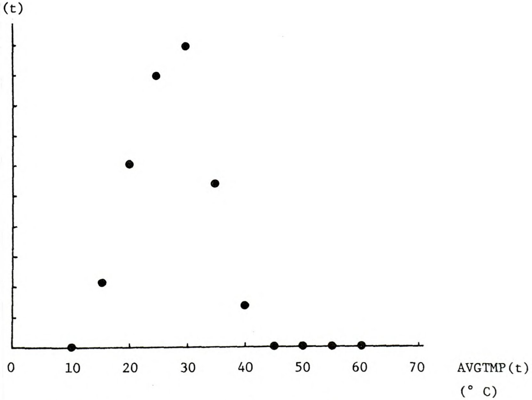


ure 5.6 Determination of the photosynthetically active quantity of plant material per unit area



ıre 5.7 Plot of points determining the temperature quality index, TPF(t), from the average temperature

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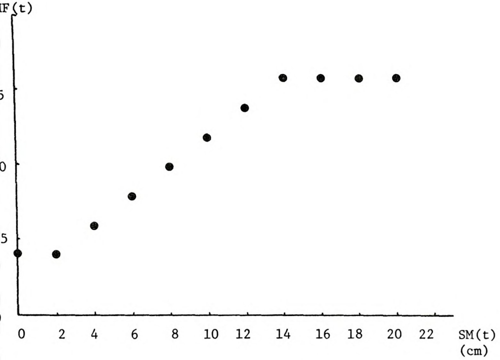
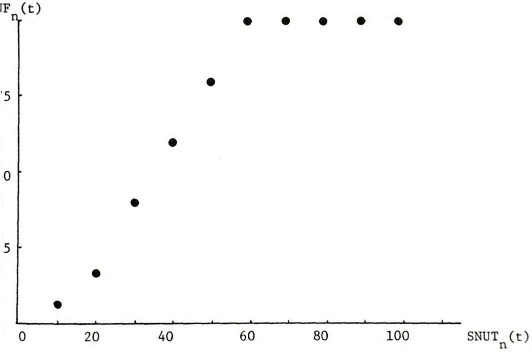


gure 5.8 Plot of points determining the soil moisture quality index, SMF(t), from the soil moisture



gure 5.9 Plot of points determining the soil nutrient quality index, $SNF_n(t)$, from the soil nutrient value

$$HOTO_n(t) \; = \; ACTIVE_n(t)*PHOMAX*SOLAR(t)*MIN \qquad (5.2.1)$$

here:

$PHOTO_n(t)$ = total plant growth rate in land parcel n--kg/hec/day

$ACTIVE_n(t)$ = active plant material in land parcel n--kg/hec

PHOMAX = conversion factor, 0.0004 kg/kg/langley/day

SOLAR(t) = solar radiation in langley/day

MIN = minimum value of TPF(t), SMF(t), and $SNF_n(t)$.

his rate must be partitioned into the proportion going to greenery rowth and the proportion going to root storage. Since the quantity f greenery and indirectly the amount in root storage in each land parcel s a function of the previous grazing and harvesting activity, the pro- ortioning factor $ZX3_n(t)$ is determined separately for each land parcel.

$$X3_n(t) \; = \; PAR3 + PAR4*(1.0 - e^{-PAR5*GRN_n(t)/LAND_n}) \qquad (5.2.2)$$

here:

$ZX3_n(t)$ = proportion of $PHOTO_n(t)$ going to root storage

$GRN_n(t)$ = quantity of greenery in land parcel n--kg

PAR3, PAR4, PAR5 are constant parameters.

transfer of growth from root storage to greenery occurs at a rate hat is largely controlled by the proportions of the total plant material hat are in root storage and greenery. This accounts for the spurt of rowth observed after a field has been heavily cropped as new shoots ppear from the crowns of the roots.

$${}_n(t) \; = \; PAR1*ROOT_n(t)*e^{-GRN_n(t)/PAR2*LAND_n} \qquad (5.2.3)$$

here:

$F_n(t)$ = rate of material transfer from root storage to greenery --kg/hectare/day

$LAND_n$ = area of land parcel n in hectares

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$ROOT_n(t)$ = quantity of root storage per hectare--kg/hectare

PAR1, PAR2 are constant parameters.

he net growth rates of greenery and root storage in a pure growth ituation are determined by equations 5.2.1 - 5.2.3; these result in

$$\frac{GRN_n(t)}{dt} = (PHOTO_n(t)*(1.0 - ZX3_n(t)) + F_n(t))*LAND_n \tag{5.2.4}$$

$$\frac{ROOT_n(t)}{dt} = PHOTO_n(t)*ZX3_n(t) - F_n(t). \tag{5.2.5}$$

This component model is not directly concerned with these pure rowth equations. It is, however, the base on which consumption by nimals and harvest by machine can be built. $AHR_n(t)$ describes the rate f consumption of greenery in land parcel n by grazing animals, while $HR_n(t)$ describes the rate of greenery removal through harvesting. Both f these variables have units of kilograms per day. Neither grazing nor arvesting is a pure consumption process; there is waste from trampling, eces, dropping of cuttings, etc. A waste factor is used to model this ccurence. MWF is a mechanical waste factor, with value 1.10, that is onsidered constant for all levels of forage harvesting. $AWF_n(t)$ is a aste factor for the grazing process; its value is a function of the tocking rate in a particular land parcel n. Stocking rates represent he number of animals per unit area of land. This model uses the control ariable, $PDSTRB_{ni}(t)$, to describe the proportion of the population of ohort i grazing in land parcel n. Equation 5.3.6 determines the tocking rate for land parcel n.

$$TOCKL_n(t) = \frac{1}{LAND_n} * \sum_{i=1}^{9} PDSTRB_{ni}(t)*POP_i(t) \tag{5.2.6}$$

:e:

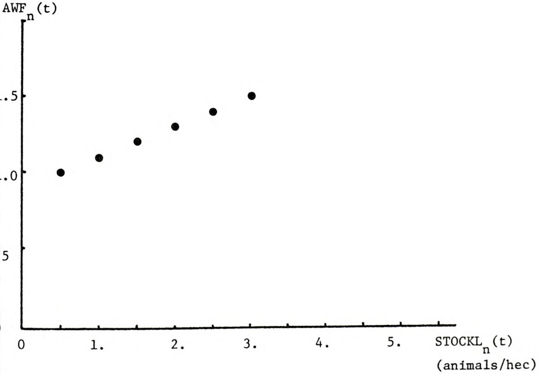
$STOCKL_n(t)$ = the stocking rate of grazing animals in land parcel n -- #/hectare

$PDSTRB_{ni}(t)$ = the proportion of the population of cohort i which is grazing in land parcel n

$POP_i(t)$ = the population of cohort i

$LAND_n$ = size of land parcel n -- hectares.

ıre 5.10 illustrates the relationship between stocking rates and grazing waste factor, $AWF_n(t)$. As the stocking rate increases, waste factor is also increased reflecting greater impacts of cattle :he land.



'igure 5.10 Relationship between grazing waste factor, $AWF_n(t)$, and the stocking rates, $STOCKL_n(t)$

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roduction of these sources of greenery consumption and their pective waste factors concludes the factors which affect the nge of greenery in pasture. This gives the net growth rate d in the model,

$$\frac{N(t)}{t} = \left\{PHOTO_n(t)*(1.0 - ZX3_n(t)) + F_n(t)\right\}*LAND_n - AWF_n(t)*AHR_n(t) - MWF*MHR_n(t) \qquad (5.2.7)$$

The quantity and the quality of forage growth consumed by animals equally important. $DIGEST_n(t)$ describes the quality of forage in d parcel n in terms of total digestible nutrients (TDN) on a dry sis. Digestibility is a dynamic variable that reflects time changes average plant composition and in actual changes in the energy value the individual parts. Since this model does not maintain forage ntities on the basis of constituent parts, a less rigorous approach digestibility must be used. Digestibility is modeled as a function three factors: relative age of green material, time of season, d density of greenery per animal grazing. The base digestibility ue (in terms of % TDN on a dry matter basis) is determined by relative age of green material in a particular land parcel. This el formulation assumes that the major element in the change of age digestibility over time is a process of decline associated h the length of time since growth first started. Time in the wing season and greenery density per grazing animal are viewed as ondary factors modifying the base digestibility value. Mathemati-ly, forage digestibility is described by

$$EST_n(t) = BASEDG_n(t)*FRQUAL(t)*FDENSE_n(t) \qquad (5.2.8)$$

wh

re:

$DIGEST_n(t)$ = forage digestibility of green plant material in land parcel n as % TDN

$BASEDG_n(t)$ = base forage digestibility determined from the relative age of forage greenery in land parcel n

$FRQUAL(t)$ = seasonal digestibility factor modifying the base digestibility value $BASEDG_n(t)$

$FDENSE_n(t)$ = forage density digestibility factor modifying the base digestibility value $BASEDG_n(t)$.

The base digestibility of forage in any land parcel is deter- ed by linear interpolation between data values representing digesti- ity versus relative age. The argument used to obtain the resultant ige digestibility value is the variable $PINDEX_n(t)$. This variable in index representing the amount of time that would be required the current forage quantity in a land parcel to be grown at the rent rate of growth existing within that land parcel. Mathemati- ly,

$$DEX_n(t) = \frac{GRN_n(t)}{\frac{dGRN_n(t)}{dt}} \qquad (5.2.9)$$

index is able to represent the major situations in plant growth ising the ratio of current quantity over the rate of change of quantity. Figure 5.11 graphically plots the relationship between and digestibility which is the key to this model of plant quality. an be seen from the graph, the plot is a monotonic decline in ge quality with increasing relative age. This formulation in unction with equation 5.2.9 is able to correctly represent the ity of forage over time. For example, if during a period of high th mechanical harvest were to severely reduce the quantity on hand,

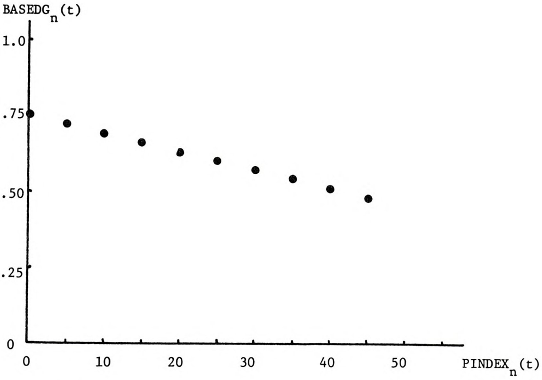
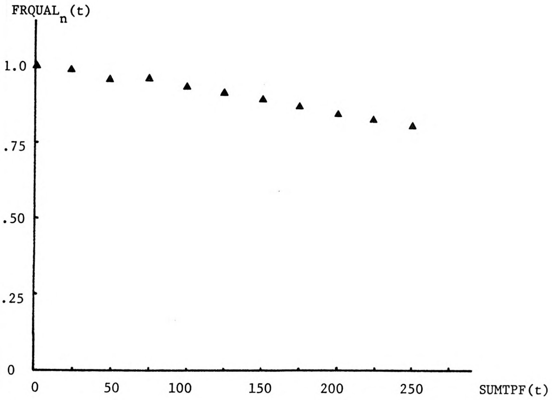


Figure 5.11 The intermediate digestibility, $BASEDG_n(t)$, as a function of pseudo-age, $PINDEX_n(t)$

en the relative age determined by equation 5.2.9 would be quite w. Using the plot of Figure 5.11 gives the correct fact of relative- high forage quality. Others cases encountered in forage growth tuations are also handled by this model of forage digestibility well. Although the relative age of forage is important in determin- g digestibility, it is not sufficient. There are qualitative differ- ces in the new growth over the length of the growing season and in the rticular growing conditions encountered. This factor is incorporated to the model through use of a multiplicative forage quality factor QUAL(t). FRQUAL(t) is determined by integrating the value of TPF(t) er the length of the growing season and using that integral value determine an index of the degree of plant maturity attained.



igure 5.12 The growth quality factor, FRQUAL(t), as a function of the integral of the temperature index over the growth season

$$TPF(t) = \int_{TSPRNG}^{t} TPF(\tau)d\tau \qquad (5.2.10)$$

re:

SUMTPF(t) = the integral of the temperature quality factor over the growth season to current time t

TPF(t) = the temperature quality factor as determined from use of Figure 5.7 and the average temperature

TSPRNG = time at which spring growth begins.

TPF(t) is used as the argument for another use of the table func-

n TABLIE[23] to determine the value of FRQUAL(t). Figure 5.12 indi-

es the relationship between SUMTPF(t) and FRQUAL(t) graphically.

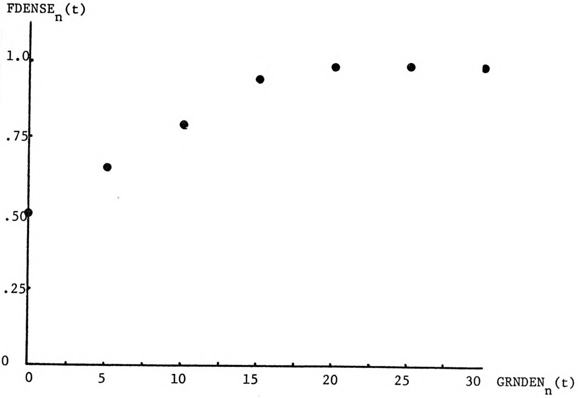


Figure 5.13 Plot of the forage density digestibility factor against per animal density

The final factor modifying the base digestibility value is NSE$_n$(t)--the influence of the current amount of forage per animal digestibility. The value of this density factor--GRNDEN$_n$(t)--is d as the arguement to obtain FDENSE$_n$(t) by linear interpolation ween data values as represented in Figure 5.13.

$$\text{DEN}_n(t) = \frac{\text{GRN}_n(t)}{\text{STOCKL}_n(t)*\text{LAND}_n*\text{DAYS}} \quad (5.2.11)$$

re:

STOCKL$_n$(t) = animals grazing in land parcel n--#/hectare

LAND$_n$ = number of hectares in land parcel n

GRN$_n$(t) = greenery in land parcel n--kg

GRNDEN$_n$(t) = forage density per grazing animal--kg/animal.

This development concludes the description of the model for etermination of forage digestibilities; three factors have been hown to be important to this modeling effort: relative age of orage in land parcels, season of the year, and the density of orage available for grazing in each land parcel.

Two state variables remain to be defined before this component odel's description is complete. SM(t) is a variable describing the mount of soil moisture. $SNUT_n(t)$ is a variable describing the amount f soil nutrients. The rate of change of soil moisture is dependent n three factors:

$$\frac{SM(t)}{dt} = RAIN(t) - EVAP(t) - PERC(t) \tag{5.2.12}$$

here:

SM(t) = soil moisture at its current level--cm in effective root depth

RAIN(t) = rainfall in cm/day

EVAP(t) = evaporation in cm/day

$= a*AVGTMP(t)^2$

PERC(t) = percolation beyond root depth in cm/day

$= b*\left(1.0 - e^{-SM(t)/c}\right)$

a, b, c are constant parameters.

he rate of change of soil nutrients is a function of the rate of hotosynthetic energy conversion and of fertilizer application to the oil. This implies that the greater the growth rate, the larger is he withdrawal of nutrients from the soil.

$$\frac{SNUT_n(t)}{dt} = SPFERT - \beta*PHOTO_n(t) \tag{5.2.13}$$

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$SNUT_n(t)$ = current level of soil nutrients in land parcel n

SPFERT = rate of applicatin of fertilizer per unit of land

$PHOTO_n(t)$ = rate of photosynthetic energy conversion in land parcel n

β = a constant parameter.

This forage growth component model is relatively crude. It vides the basic elements needed to evaluate realistic grazing agement strategies but could be improved considerably. This model also very empirical, as is evidenced by the extensive use of TABLIE look up interpolations between data values. The data values used uld, and could, be tuned to a particular location. Figure 5.14 a block diagram of the entire component model. This figure is a venient way to trace the interconnection of the model variables they have been described in this section.

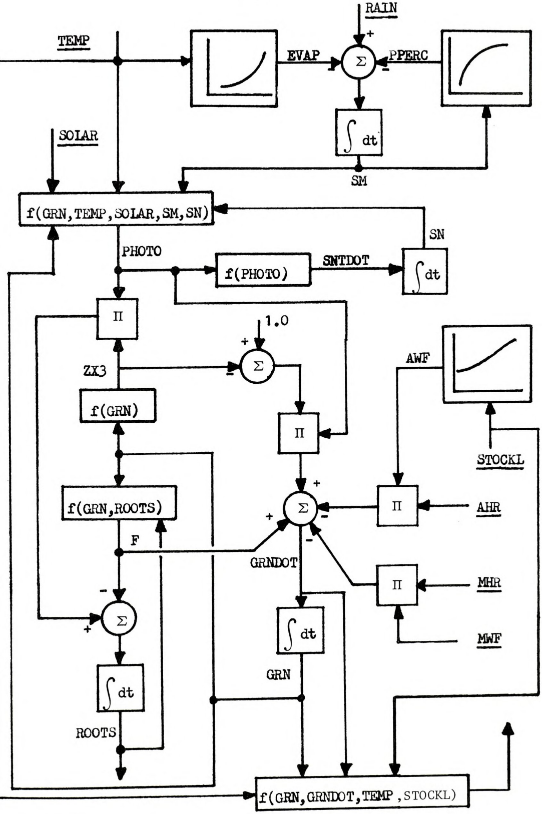

Figure 5.14 Block diagram of the forage growth component

Feed Stock Component

The feed stock component consists of basic accounting for the .ous activities involving feed stocks. Chapter IV, section 2, :ribed these activities. Subroutine FEEDS performs this accounting :he enterprise simulation model.

Quantities of feed stocks are represented by the variable $FSTOCK_n(t)$. equation determining current feed stock levels uses the previous :l, the amounts bought and sold, the amounts fed to cattle, and the ınt lost through waste and pests. Thus

$$)CK_n(t) = FSTOCK_n(t-dt) + STKPUR_n(t-dt) + CROP_n(t-dt) - CSALES_n(t-dt) - STKFED_n(t-dt) - FRCLOS_n*FSTOCK_n(t-dt)*DT \quad (5.3.1)$$

:e:

$FSTOCK_n(t)$ = current quantity of feed stock n -- kg

$STKPUR_n(t)$ = quantity of feed stock n purchased -- kg

$CROP_n(t)$ = quantity of feed stock n produced -- kg

$CSALES_n(t)$ = quantity of feed stock n sold -- kg

$STKFED_n(t)$ = quantity of feed stock n fed to cattle -- kg

$FRCLOS_n$ = annual rate of loss of feed stock n

DT = length of simulation time increment -- years.

of the sources of increase or decrease for $FSTOCK_n(t)$ except losses determined in other model components. $FRCLOS_n$ is a constant fracal loss rate assumed to be uniform over the entire year.

The digestibility of feed stocks in terms of a TDN value are lied by $FQUAL_n(t)$. Changes in quality are a result of purchases, production, and spoilage. Spoilage is assumed to mean that the ty of the crop declines over time. $SPOIL_n$ is an annual frac-

l decline in quality of crop n; like $FRCLOS_n$ it is assumed to

nstant over time. $FQUAL_n(t)$ is determined by

$$ _n(t) = \frac{FQUAN*FQUAL_n(t-dt)*SPOIL_n*DT}{FSTOCK_n(t)} + \frac{PRQUAL_n(t)*STKPUR_n(t) + CROP_n(t)*CROPQL_n(t)}{FSTOCK_n(t)} \qquad (5.3.2)$$

e:

$FQUAN = FSTOCK_n(t-dt) - CSALES_n(t-dt) - STKFED_n(t-dt)$

$PRQUAL_n(t)$ = the TDN value of feed stock n purchases

$CROPQL_n(t)$ = the TDN value of feed stock production.

The final variable determined in this component is the total

ıal crop production of feed stock n, namely $CROPG_n(t)$. This

ue gives a running total of the production to date and could be

pared with $XCPROD_n(t)$ to obtain an estimate of the quantity of

d stock n that might yet be harvested in this growing season.

$$ PG_n(t) = \int_{TSPRNG}^{t} CROP_n(\tau)d\tau \qquad (5.3.3)$$

Figure 5.15 is a block diagram illustrating the total inter-

ationship between variables that are included in this component

el of feed stocks.

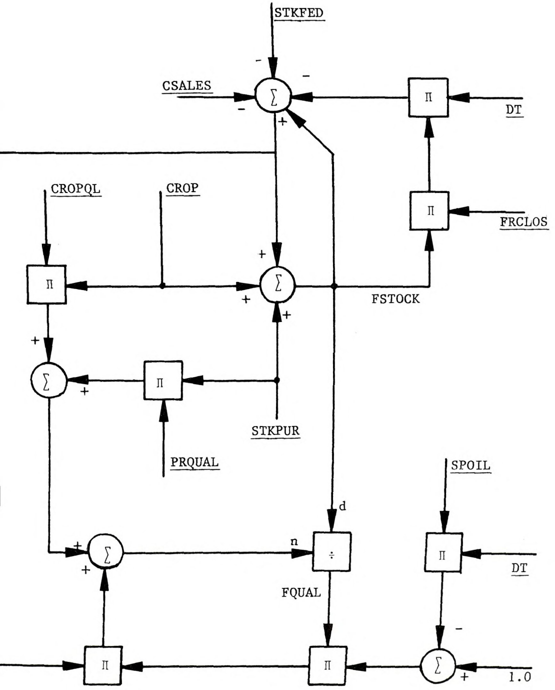

Figure 5.15 Block diagram of the feed stock component.

4 Nutrient Impact Component

The model for this component develops the impacts of nutrient take in two areas: reproduction and growth. The nutrient impacts at are modeled are those related to energy; protein requirements well as vitamins and trace minerals are assumed to be available in ufficient quantities that energy is the predominant variable of interest. The majority of this component is contained in subroutine UTRN, and is described in Schuette[48]. This thesis will not present hose results except as they interact with the remainder of the system odel.

Feed quantities and qualities are a prime concern of this component. Feed is described in terms of four variables for each herd cohort: (1) $CNCAL_i(t)$--the quantity of concentrates allocated to cohort i, (2) $RHGAL_i(t)$--the quantity of roughages allocated to cohort i, (3) $TDNC_i(t)$--the average TDN value of the concentrates allocated, and (4) $TDNR_i(t)$--the average TDN value of the roughages allocated to cohort i. These variables are inputs to subroutine NUTRN which then determines the impact of these feed inputs. NUTRN returns several variable values: $TDMIC_i(t)$--quantity of concentrates actually consumed by cohort i, $TDMIR_i(t)$--quantity of roughages actually consumed by cohort i, and $DGAIN_{ij}(t)$--the rate of daily gain by the jth subpopulation of cohort i as a result of the interaction of its feed intakes of energy and requirements for energy.

Total roughage allocation to any cohort is composed of feeds from grazing as well as those from feed stock allocations. Usually these sources are disjoint, but there are some conditions under which grazing would be supplimented by feed stocks. The procedure used here is to

mine the roughage allocation as a result of the grazing distri-
n of the herd, and add to it the voluntary feed allocations. The
. grazing roughage allocation for the ith cohort is then

$$AL_i(t) = \sum_{n=1}^{NLANDS} \left| \frac{PDSTRB_{ni}(t)*POP_i(t)*GRN_n(t)}{\sum_{\ell=1}^{9} PDSTRB_{n\ell}*POP\ (t)} \right| \quad (5.4.1)$$

e:

$FORGAL_i(t)$ = current forage available to the ith cohort as a result of its distribution over the land parcels -- kg

$GRN_n(t)$ = total quantity of greenery in land parcel n -- kg

$PDSTRB_{ni}(t)$ = fraction of the population of cohort i which is grazing in land parcel n

$POP_i(t)$ = current population of cohort i.

digestibility of this allocation in terms of TDN is a function of
forage digestibilities in each land parcel.

$$TDN_i(t) = \sum_{n=1}^{NLANDS} \left| \frac{PDSTRB_{ni}(t)*POP_i(t)*GRN_n(t)*DIGEST_n(t)}{\sum_{\ell=1}^{9} PDSTRB_{n\ell}(t)*POP_\ell(t)*GRN_n(t\ )} \right| \quad (5.4.2)$$

re:

$FORTDN_i(t)$ = digestibility of the $FORGAL_i(t)$ allocation in TDN

$DIGEST_n(t)$ = the TDN digestibility value of the forage in land parcel n.

Addition of the roughage from grazing and the voluntary allocation
es the total roughage allocation to cohort i,

$$AL_i(t) = FORTDN_i(t) + FEEDAL_i(t) \quad (5.4.3)$$

ch has a digestibility value determined by the weighted average of
different sources of the roughage.

$$(t) \quad = \quad \frac{FEDTDN_i(t)*FEEDAL_i(t) + FORTDN_i(t)*FORGAL_i(t)}{FEEDAL_i(t) + FORGAL_i(t)} \qquad (5.4.4)$$

e:

$FEDTDN_i(t)$ = the average TDN value of the roughage voluntarily allocated to cohort i

$FEEDAL_i(t)$ = the roughage allocation voluntarily given to herd cohort i -- kg/DT.

Determination of the value of $FEDTDN_i(t)$ and $TDNC_i(t)$ requires the allocation of TDN from roughage and of TDN from concentrates related to the actual physical quantities of feed stocks that are . This results in

$$C_i(t) \quad = \quad \frac{CATTIN_{1i\ell}(t)*POP_i(t)*DAYS}{CNCAL_i(t)} \qquad (5.4.5)$$

$$TDN_i(t) \quad = \quad \frac{CATTIN_{2i\ell}(t)*POP_i(t)*DAYS}{FEEDAL_i(t)} \qquad (5.4.6)$$

re:

$TDNC_i(t)$ = average TDN value for the concentrate allocation to cohort i

$FEDTDN_i(t)$ = average TDN value of the roughage allocation to cohort i

$CATTIN_{1i\ell}(t)$ = quantity of TDN allocated to each member of cohort i per day from concentrates under plan ℓ

$CATTIN_{2i\ell}(t)$ = quantity of TDN allocated to each member of cohort i per day from roughages under plan ℓ

$CNCAL_i(t)$ = physical quantity of concentrates allocated to the ith cohort -- kg/DT

$FEEDAL_i(t)$ = physical quantity of roughages allocated to the ith cohort -- kg/DT

DAYS = number of days in a simulation time increment.

units of the variables $FEDTDN_i(t)$ and $TDNC_i(t)$ are kg TDN/kg feed,

lowing directly from their definition as the average TDN value of uantity of feed stocks fed to cattle.

Determination of the actual quantity of feed stocks fed to cattle each time increment of the simulation requires knowledge of the ired distribution of the TDN allocations over the possible feed stocks sting. The control variables $CNCFRC_{in}(t)$ and $RHGFRC_{in}(t)$ are used management to distribute the cohort allocations of concentrates and ghages over the range of available feed stocks. $STKFED_n(t)$ is the iable used to represent the actual quantity of feed stock n used for tle feeding in the current time increment of the simulation. This iable is not a rate but a quantity, as are all variables affecting current quantity of feed stock n on hand--$FSTOCK_n(t)$. Since the d stock variables include both roughages and concentrates in a single ting, the following equation determines the amount of feed stock n d for cattle consumption in this time increment.

$$FED_n(t) = DAYS* \sum_{i=1}^{9} POP_i(t)* \left[CATTIN_{1i}(t)*CNCFRC_{in}(t) + CATTIN_{2i}(t)*RHGFRC_{in}(t) \right] * \frac{1}{FQUAL_n(t)} \qquad (5.4.7)$$

re:

$STKFED_n(t)$ = quantity of feed stock n fed to cattle in this DT

$CNCFRC_{in}(t)$ = fraction of the TDN allocation of concentrates to cohort i derived from feed stock n

$RHGFRC_{in}(t)$ = fraction of the TDN allocation of roughages to cohort i derived from feed stock n

$FQUAL_n(t)$ = current TDN value of feed stock n

$POP_i(t)$ = current population of cohort i.

Equation 5.4.7 brings together the actual quantities of feed cks that have been used to feed cattle. It combines the consumption roughages and concentrates in one single equation, but since this

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a mutually exclusive description there is no overlap to cause oblems. Therefore, the matrices CNCFRC(t) and RHGFRC(t) are con-ructed so that when the in^{th} element of one is nonzero, the in^{th} ele-nt of the other is zero. Additionally, the rows of both of these trices must sum to one if any allocation is to be made. This require-nt exists because either a row of CNCFRC(t) or RHGFRC(t) represents e fraction of the cohort allocation that is drawn from each of the ed stocks. A final note concerning the use of the feed stocks for nsumption--this model assumes that the entire amount of the feed ock allocated for consumption is used. Any quantities allocated to e herd or a specific cohort which are not consumed are assumed to be mpletely wasted.

The consumption characteristics of the herd cohorts determine ether the allocations to the herd are completely consumed or not. en the herd is not grazing, any excess allocation over consumption is tally wasted. When the herd is grazing, however, a differentiation st be made between nutrient intakes from grazing and from voluntary eding. The following priority of cattle consumption preferences is sumed to hold: (1) cattle prefer concentrates to roughages, and (2) ttle prefer feed stock roughages to grazed roughages. Differential eferences among feed stocks are assumed to be negligible, although ey do in fact exist. The consumption of roughages by the herd which e not covered by voluntary roughage allocations comes from grazing. is grazing removal of forage must also be distributed across the ifferent land parcels being grazed. The variable $PDSTRB_{ni}(t)$, which as used to obtain the stocking rates in the land parcels, is used here distribute the forage removal by grazing over the land parcels.

$$HR_n(t) = \sum_{i=1}^{9} [PDSTRB_{in}(t)*(TDMIR_i(t) - FRAC*FEEDAL_i(t))] \qquad (5.4.8)$$

here:

$TDMIR_i(t)$ = actual roughage consumption of cohort i

$AHR_n(t)$ = grazing removal of forage from land parcel n

FRAC = proportion of roughages consumed that are from voluntary feed sources

$$= \begin{cases} SPLIT, \text{ if } RHGAL_i(t) > FEEDAL_i(t) \\ 1.0, \text{ otherwise} \end{cases}$$

SPLIT = a parameter based on cattle preferences.

Variables internal to subroutine NUTRN maintain the reproductive ondition of each subpopulation of the breedable female cohorts. See chuette[48] for a complete discussion of this model. Reproductive ffects on male breeding cohorts have been ignored up to this point in he model's development. When breeding activity occurs, the variables PAT_{ijk} and $CTIM_{ijk}$ describe the resulting pattern of pregnancy rate nd timing for the jth subpopulation of cohort i from its kth servicing. he variables are used in subroutine BIRAT of the population demography omponent to develop overall cohort birth curves.

The simulation model of this component is the subroutine CONSUM. he subroutine develops values for $STKFED_n(t)$, $AHR_n(t)$, $DGAIN_{ij}(t)$, and eproductive impacts reflected in the values of $CTIM_{ijk}$ and $CPAT_{ijk}$ hen breeding occurs. Figure 5.16 represents a block diagram of the ubroutine CONSUM.

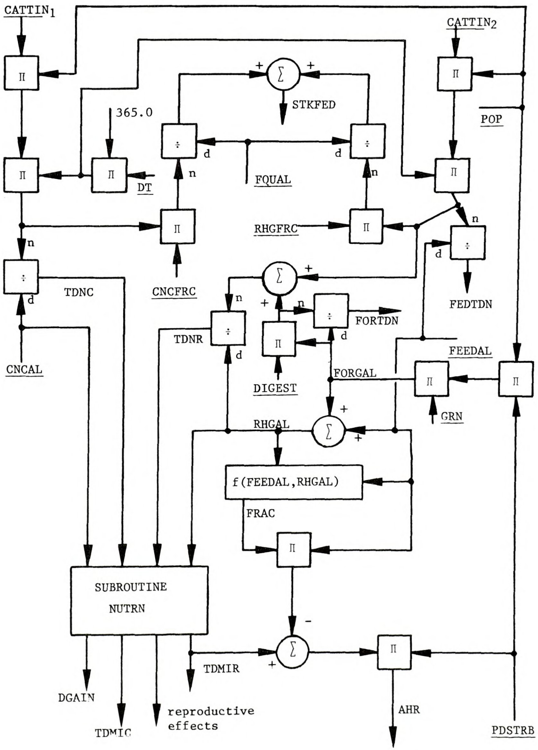

Figure 5.16 Block diagram of the nutrient impact component.

7.5 Management Decision Making Component

This section will provide the full details of the model of the management component. As outlined previously, management decisions have been separated into two discrete groups; those decisions which can be determined endogenously using standard economic criteria and those whose nature is not so obviously solvable. This latter group of decisions is acted on by the user of the model through exogenous supply of control variable values. The purpose of this section is to explain the details about how decision points--times when exogenous control is exercised—are recognized, to give the form of the equations for carrying out specific decisions, and to review the criteria for endogenous decision making.

Four of the five decision points are organized around physical events; these are the onset of spring growth, breeding, weaning, and culling. These will usually occur in the order listed above, but not necessarily so. The fifth decision point is the occurrence of an event requiring the attention of the model user. These are fall feed stock supplies unsynchronized with feeding plans, feed stocks unable to carry the herd for two DT time increments, and working capital falling below acceptable levels.

One characteristic which makes decision making difficult at these five points is the fact that the prices the manager expects play a key role in the action he takes. An additional complication is the uncertainty in knowing how to act with regard to husbandry activities such as weaning, culling, and breeding. The very long time delays involved in the production of marketable cattle (at whatever stage of maturity) and in the introduction of replacement breeding animals imply that the manager must guess the future market and hope he does so correctly. The response of many managers is to go with the current price as a guide for future desired production. This results in wide industry supply fluctuations (and thereby price fluctuations) over a multi-year cycle. This cyclical behavior exists to some extent in all livestock products and is partly a result of the uncertainty (due to the delay lengths) that long production lead times bring to decision making. This component model is therefore organized to recognize decision points, to allow the user to make his own judgmental decision, and to determine all other decisions internally using standard economic criteria.

Organization of this component model can be easily understood through review of Figure 4.9. In every time increment of the simulation model subroutine INQUIR attempts to determine whether any of the five forms of decision point currently exist. Figure 5.17 illustrates the construction of INQUIR. In each DT simulation time increment the current time value is checked against each of the five possible time points that constitute decision points--TSPRNG, TBRD(1), TBRD(2), TWEAN, and TCULL. Additionally, the three criteria that call for a special decision point are checked. If any of them are true, then the special decision point is called by setting IFLAG equal to 2, while IFLAG is set to 1 at any of the regular decision points. If the IFLAG variable value is not equal to zero at the conclusion of the decision point checks, then INQUIR creates a permanent file of

all values that are needed to preserve the simulation in its current state. This permanent file is available for access at any time to restart the time simulation exactly where it left off. If the IFLAG value is still zero (as it was set as the initial action in the subroutine) at the end of all decision point checks, then control skips from subroutine INQUIR to subroutine NORMAL.

Subroutine INQUIR is constructed (again see Figure 5.17) so that each decision point is checked every DT increment of simulated time so that multiple decision points at any one time can be detected. An example of this is the event of weaning and culling occurring at the same time. INQUIR will have gotten all the way through its structure to the point of checking whether time is equal to TWEAN; since this is true, the if statement branches to YES, IFLAG is set equal to one, and the detailed states of the model and any other information that the decision maker might need to make a decision are printed onto the output file for the user to observe. Following the logic of INQUIR, the checking of time for equality to TCULL is the next operation. The if statement check is true, then the logic path of YES is followed. This logic branch results in additional printing of state variable and other decision information, but the printing for each decision point is tailored for that decision point resulting in some new information being made accessible to the decision-maker. In practice the values of TBRD(1) and TBRD(2) are also likely to be equal; that is why the logic of INQUIR bypasses part of the YES branch of the TBRD(2) if statement check when time has already been

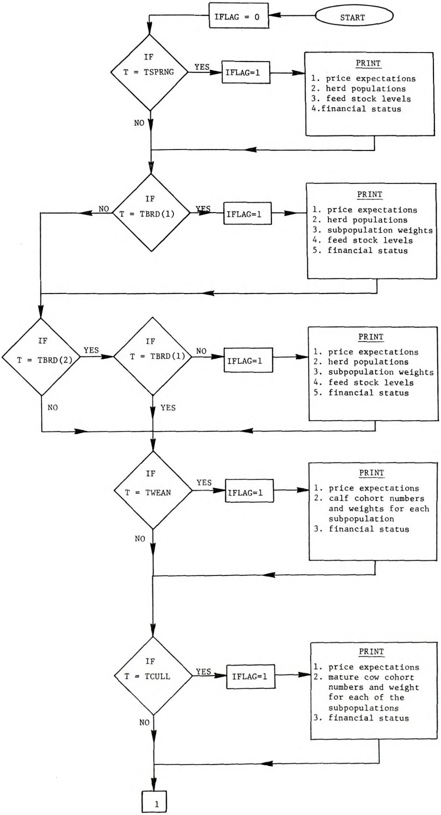

Figure 5.17 Flow chart of subroutine INQUIR of the management component

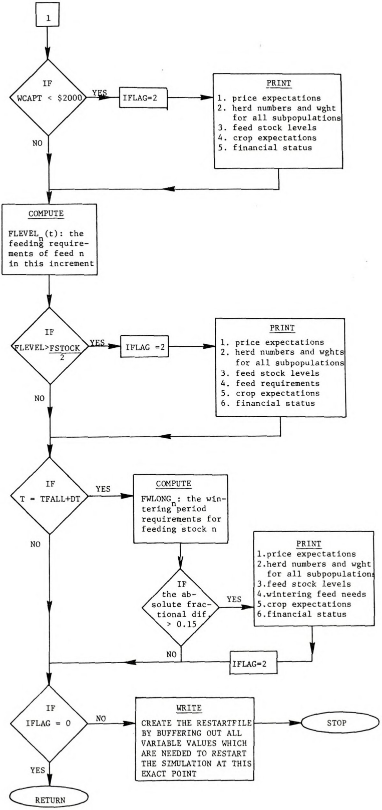

Figure 5.17 (cont'd.)

recognized as equal to TBRD(1), thus setting the value of IFLAG to one. The logic of INQUIR has been developed so that multiple decision points existing at a particular point in simulated time can be detected and acted upon. Subroutine RESPNS, which reads in control variable values, has a parallel structure to subroutine INQUIR.

Exogenous Decision Making

When a decision point has been detected, the decision information printed, the permanent file constructed, and the simulation stopped, the user makes his decisions based on any decision rule or intuitive feeling that he desires. Once he has made his decisions for a particular decision point and the data cards for the control values are prepared, the user restarts the simulation by reading from the permanent file to fix all model variable values just as they were when the decision point(s) was detected. The next step is to read the control variable values; subroutine RESPNS accomplishes this action. Figure 5.18 is a flow chart illustrating the construction of subroutine RESPNS.

Subroutine RESPNS is constructed parallel to the structure of subroutine INQUIR; the control variables that are read in to direct the enterprise's operation at each decision point follow the input formats in User's Guide to the Beef Cattle Enterprise Simulation Model. When current time is equal to a decision point time, or when the value of IFLAG is two, then the logic path follows the YES branch from the if statement. The first action is to read the control variable values which apply for that decision point from the user supplied data cards; the second action is to perform any execution statements that are peculiar to that decision point. An example of such specialized execution statements is the action to wean the calf cohorts; here the

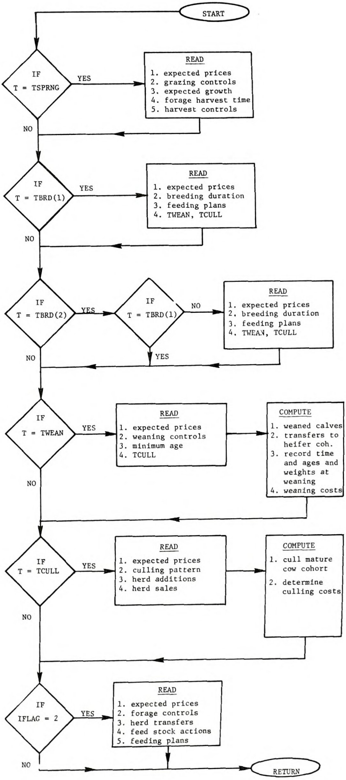

Figure 5.18 Flow chart of subroutine RESPNS of the management component

control variable $TFRAC_{\ell i}(t_{wean})$ is used to transfer a fraction of the ℓth female calf subpopulation to the ith heifer cohort. Similar execution statements are required to cull the mature cow cohort using the control variable $CULFRC_j(t_{cull})$. When any necessary execution statements have been completed for a particular time related decision point, the logic path proceeds with the determination of the existence of other decision points in this simulation time increment. If a special decision point has been detected by subroutine INQUIR, then the value of IFLAG is two. If IFLAG has a value of two, then subroutine RESPNS branches to the YES side of the final if statement check, reads in any control variable values required, and performs any needed execution statements. At the conclusion of this step, the YES branch logic path rejoins the main flow within the subroutine; the last action is then to exit from the subroutine and proceed with the normal logic flow of the overall simulation model.

The final element in the management component is subroutine NORMAL; this element will be discussed in considerable detail in the last part of this section under the subtitle "Endogenous Decision Making." Control is transferred to NORMAL from two points; first, from subroutine INQUIR if no decision points have been encountered in the current time increment. The second referral point for subroutine NORMAL is after subroutine RESPNS has completed its reading of control variable values and executed any statements carrying out the user's decisions.

Spring growth onset and breeding decision points require the user to specify the value of various expectation and control values that will have long term effect on the enterprise's behavior. At the time spring

growth begins the user must specify several control variables that will influence the use of forage and its growth over time. $PDSTRB_{ni}(t)$ controls the stocking rates on each of the land parcels through specification of the fraction of the population of cohort i that grazes on land parcel n. Equation 5.2.6 illustrates this effect. $TMHR_k$ specifies the times at which forage is to be mechanically harvested, while REMOVL controls the amount harvested. $XCPROD_n$ and $XCQUAL_n$ provide information to the model about the expected amount and quality (TDN) of crop n that will be harvested in this growing season. This includes forage growth as well as feed crops.

Breeding is the activity of the enterprise that is most affected by the uncertainties of cattle and feed stock prices. At this time the manager must decide how his reproductive females will be bred, the duration of the breeding period, and which animals are to be bred. These decisions are very complex since they are ultimately conditional on the prices that will occur in the market for cattle and for feed stocks in the interval between the beginning of this breeding period and the soonest date for calf sales. Moreover, the relationships between feed stock intake rates over time and the success of breeding, and between feed stock intake rates and weight gains of growing cattle are so complicated that only use of a simulation model of the herd is likely to correctly develop the impacts of breeding and feeding policies on calf numbers and weights. Knowledge of the physical outcomes of different feeding and breeding policies would then be combined with expected prices to obtain predictions of financial outcome conditional on the prices used. This simulation model can accomplish this investigation through use of the decision point mechanism developed to permit

just this sort of evaluation of control strategy alternatives.

When the breeding decision point is reached, the management component recognizes this fact and creates the restart file of simulation variable values. It has also printed current state variable values to allow the user to have a complete picture of the current condition of the enterprise. The user makes the decisions about breeding and feeding policies he wishes to follow and restarts the model to determine the results of his decisions over time. When the next decision point of the simulation is reached this procedure is repeated. The user proceeds in this manner until the final time horizon has been reached for evaluation of the breeding and feeding policies he is investigating. He can then return to the restart file from which he started and repeated this entire procedure using a different set of control variable values representing a different breeding policy. By utilizing this sort of procedure to investigate the alternative breeding and feeding policies the user should be able to select one that is best for the price expectations and other assumptions he is using. Figure 4.11 illustrates the sort of alternative routes that can be developed using the decision point mechanism.

The control variables that the user enters at the breeding decision point are (1) $DURB_i(t)$--the duration of the breeding interval for the ith female cohort, (2) $FPLANS_\ell(t)$--the times at which the feeding plans for the herd end, (3) $CATTIN_{ik\ell}(t)$--the feeding rates for the cohorts under the different feeding plans, and (4) $DISTFD_{in\ell}(t)$--the proportions of the desired TDN feeding levels to come from specific feed stocks under the alternative feeding plans.

Weaning is an event which requires extensive calculation to carry out the user's decisions. At the time of weaning, the population of calves (both male and female) will be spread among numerous subpopulations of cohorts 7 and 8. The user specifies how he wants these calves used through the variables AGEMIN and $TFRAC_{\ell i}(t)$. AGEMIN is the minimum age that is to be weaned. This variable is included to allow control over weaning in extended calving seasons, where calves may be present in the entire range of subpopulations of the calf cohorts. $TFRAC_{\ell i}(t)$ is the fraction of female calves in subpopulation ℓ that are to be transferred to cohort i. In all cases the index ℓ refers to the ℓ^{th} subpopulation older than the minimum weaning age, and i refers to cohorts 2 or 3--the replacement heifer and bred heifer cohorts.

An important consideration in the mechanics of weaning is to preserve the age distribution that has been maintained in the calf cohorts following transfer to the heifer cohorts. This age distribution is important to future determination of puberty in heifers, which is largely a function of age and weight. Discrete delays are used in the calf and reproductive heifer cohorts to allow the population to be recorded strictly on the basis of age, not on the basis of relative maturity as is done in the other herd cohorts. The individual stage delay length for the delay models of the calf and replacement heifer cohorts are equal so as to keep the same level of fineness of the age distribution. Figures 5.19 and 5.20 illustrate the way in which the variables AGEMIN and $TFRAC_i(t)$ can select from the female calf cohort to create the new entries in the replacement

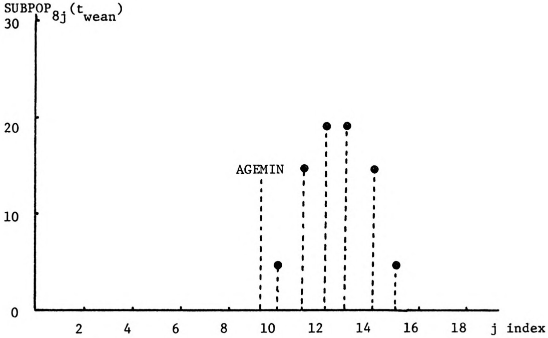

Figure 5.19 Subpopulation values from the female calf cohort prior to weaning action by management

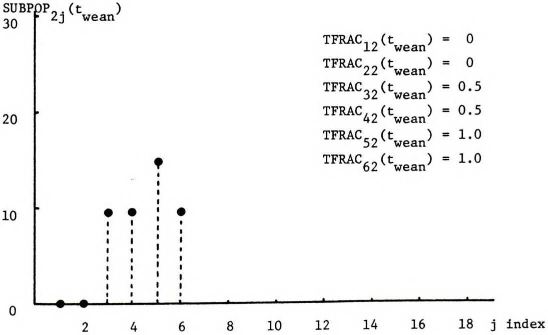

Figure 5.20 Subpopulation values from the replacement heifer cohort following weaning action

heifer and bred heifer cohorts. Figure 5.19 depicts a female calf cohort with six subpopulations older than the minimum age for weaning, AGEMIN. The table of values listed for $TFRAC_{\ell 2}(t)$, $\ell = 1,\ldots,6$ indicate the fraction of the subpopulation indexed in the ℓth position greater than the index corresponding to AGEMIN that are transferred to the replacement cohort. The result of the initial female calf cohort subpopulation distribution, and the indicated values of AGEMIN and $TFRAC_{\ell 2}(t)$, is the replacement heifer cohort subpopulation distribution given by Figure 5.20. Mathematically,

$$SUBPOP_{2\ell}(t) = SUBPOP_{8,m+\ell}(t)*TFRAC_{\ell 2}(t) \qquad (5.5.1)$$

where:

$SUBPOP_{ij}(t)$ = the population of the jth subgrouping of cohort i

$TFRAC_{\ell 2}(t)$ = the fraction of the $m+\ell$ subpopulation of cohort eight transferred through weaning to the replacement heifer cohort

m = the subpopulation index corresponding to the oldest subpopulation younger than age AGEMIN.

Similarily for the females calves weaned and sent to the bred heifer cohort,

$$SUBPOP_{3\ell}(t) = SUBPOP_{8,m+\ell}(t)*TFRAC_{\ell 3}(t) \qquad (5.5.2)$$

where:

$TFRAC_{\ell 3}(t)$ = the fraction of the $m+\ell$ subpopulation of cohort eight transferred through weaning to the bred heifer cohort.

The remaining calves in the female calf cohort older than AGEMIN are sold on the market, as are all male calves not retained for bull replacements.

Sales of cattle is partially accomplished through use of the cohort delay output variable $ROUT_i(t)$. Subroutine RESPNS makes use of this variable when carrying out sales of the weaned animals not saved for the reproductive or fattening cohorts. The current value of $ROUT_i(t)$ has been computed in subroutine HOMOG4 in the demography component. Subroutine RESPNS redefines this value to include sales animals from the entire cohort rather than only those leaving the cohort due to satisfying the required discrete delay time. Then

$$ROUT_7(t) = \left(\frac{1}{DT}\right) \sum_{j=m}^{KK_7} SUBPOP_{7j}(t) \tag{5.5.3}$$

$$ROUT_8(t) = \left(\frac{1}{DT}\right) \sum_{j=m}^{KK_8} SUBPOP_{8j}(t)*[1 - TFRAC_{j+1-m,2}(t) - TFRAC_{j+1-m,3}(t)] \tag{5.5.4}$$

where:

$ROUT_i(t)$ = annual rate of output from the ith cohort delay process

$TFRAC_{\ell i}(t)$ = fraction of the female calf subpopulation indexed $m+\ell$ transferred to the ith heifer cohort

m = the subpopulation index corresponding to the oldest subpopulation which is younger than AGEMIN

DT = time increment of the simulation--fraction of a year.

$ROUT_i(t)$, as redefined above, is used to transfer cattle between cohorts using the control variables C2, C3, C4, C5, C6, C9, C10, and C11. These equations have aggregated together many animals of different ages, and hence weights; the weight of the final subpopulation of the calf cohorts must be redefined to reflect this aggregation. Therefore

$$W_{7,KK_7}(t) = \frac{\sum_{j=m}^{KK_7} SUBPOP_{7j}(t)*W_{7j}(t)}{\sum_{j=m}^{KK_7} SUBPOP_{7j}(t)} \qquad (5.5.5)$$

$$W_{8,KK_8}(t) = \frac{\sum_{j=m}^{KK_8} SUBPOP_{8j}(t)*[1-TFRAC_{j+1-m,2}(t)-TFRAC_{j+1-m,3}(t)]*W_{8j}(t)}{\sum_{j=m}^{KK_8} SUBPOP_{8j}(t)*[1-TFRAC_{j+1-m,2}(t)-TFRAC_{j+1-m,3}(t)]} \qquad (5.5.6)$$

where:

$W_{ij}(t)$ = average weight of the j^{th} subpopulation of cohort i.

$SUBPOP_{ij}(t)$ = the number of animals in the jth subpopulation of cohort i

KK_i = the number of subpopulations in the ith cohort

$TFRAC_{\ell i}(t)$ = fraction of the female calf cohort subpopulation indexed $m+\ell$ transferred to the ith cohort.

Equation 5.5.5 is simply the weighted average of weights of male calves weaned. Equation 5.5.6 is the weighted average of female calves weaned, but which are not selected for transfer to either of the reproductive heifer cohorts. Using the variable $TFRAC_{\ell i}(t)$, the simulation model user can be selective about what calves are retained for use as replacement animals. A common strategy of enterprise operators is to choose the oldest calves for such replacements to maximize the likelihood of successful initial breeding.

The final action of these special execution statements at calf weaning is to set all $SUBPOP_{7j}(t)$ and $SUBPOP_{8j}(t)$ values to zero (for j subpopulations older than AGEMIN) to reflect the fact that these calves have been weaned and are gone.

Culling is a relatively simple process mechanically, but it has wide ranging implications on future herd reproductive characteristics. $CULFRC_j(t)$ is the fraction of the j^{th} subpopulation of the mature cow cohort that is to be culled. This control variable allows very detailed control over culling--control that can be used to remove cows which are not reproductively useful from the herd. The following equation implements culling for each subpopulation individually,

$$SUBPOP_{1j}(t) = SUBPOP_{1j}(t)*(1-CULFRC_j(t)) \qquad (5.5.7)$$

where:

$SUBPOP_{1j}(t)$ = the number of animals in the jth subpopulation of the mature cow cohort

$CULFRC_j(t)$ = the fraction of the jth subpopulation culled.

In a fashion similar to 5.5.3, the output rate of the mature cow delay is used as a vehicle for funneling the culled cows through the financial mechanism.

$$ROUT_1(t) = ROUT_1(t) + \left(\frac{1}{DT}\right) \sum_{j=1}^{KK_1} SUBPOP_{1j}(t)*CULFRC_j(t) \qquad (5.5.8)$$

where:

$ROUT_1(t)$ = the annual rate of output of animals from the mature cow delay process

$CULFRC_j(t)$ = fraction of the jth subpopulation culled

DT = the time increment of the simulation--fraction of a year.

Equation 5.5.8 differs slightly in form from 5.5.3 and 5.5.4 in that the previous value of $ROUT_1(t)$ is retained, with the culled cows being added to the former value. The reason for this difference is that in the case of culling, the cows culled are in addition to those which are leaving the delay process through old age. Weaning is an action

which is all inclusive, so that the animals exiting the calf cohort (if any) when weaning takes place are counted in the equations 5.5.3 and 5.5.4, where they would be counted twice if the form of 5.5.8 was followed.

Since the mature cow cohort is assumed to have relatively small weight differences among the various subpopulations there is no need to compute a psuedo average weight for the output rate as is done in equations 5.5.5 and 5.5.6. The weight $W_{1,KK_1}(t)$ is assumed to be a sufficiently accurate value.

Figure 5.21 illustrates an example of this culling process guided by the input of control values by the model user. Solid square points represent the overall calving rate achieved by the various subpopulations of the mature cow cohort during the previous calving season. Circular points represent a particular culling fraction to be applied against that subpopulation. This example culling pattern is guided by the desire to eliminate cows from the herd which have not calved in the previous year. The likelihood of cows failing to calve increases with previous calving failures, so elimination of such animals from the herd should raise the overall herd calving fraction. The reason for desiring a higher calving fraction is the simple goal of reducing feeding costs to achieve the same physical output. Other strategies can, of course, be followed by model users. The culling fraction for the youngest subpopulation is lower than the value indicated by the above strategy to reflect the fact that these animals were not yet mature at their first calving experience.

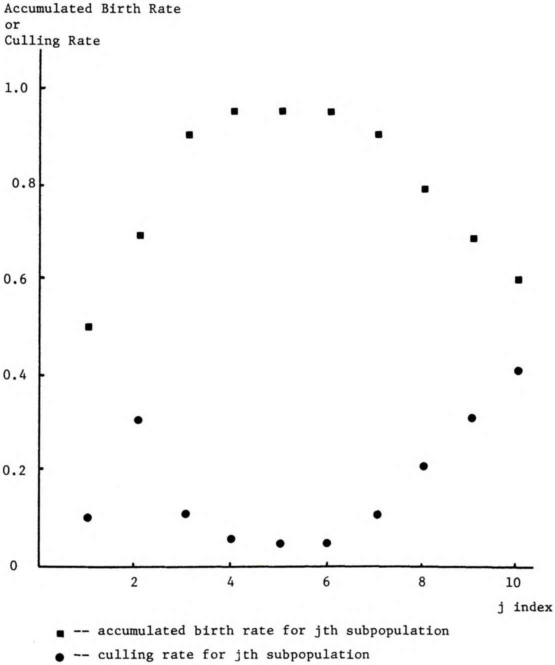

Figure 5.21 Graph of culling rates for each subpopulation of the mature cow cohort using accumulated birth rates as a guide

The manager could also be interested in adding to his herd, as well as culling some or all of it. The control variables $ASELL_i(t)$ and C2, C3, C4, C5, C6, C9, C10, and C11 are available to the user at the culling decision point to carry out any herd changes desired, whether positive or negative. Figure 5.3 illustrates how the herd maturation flow variables C2, ..., C11 affect the herd. $ASELL_i(t)$ is the proportion of the current herd population of cohort i that is to be sold in this time increment. Then

$$ADDRT_i(t) = \frac{-ASELL_i(t)*POP_i(t)*(1-DR_i(t)*DT)}{DT} \qquad (5.5.9)$$

where:

$ADDRT_i$ = the annual rate of additions to cohort i

$POP_i(t)$ = the current cohort i population

$DR_i(t)$ = the annual cohort i death rate

DT = the simulation time increment

$ASELL_i(t)$ = proportion of the population of cohort i that is to be sold in this time increment.

"Special decision point" is the term used to designate three events that require the interactive attention of the model user. The first of these is post-harvest feed stock levels incompatible with the planned feeding rate through the end of the wintering season. The second of these is feed stocks insufficient to meet the planned feeding over a short interval into the future, eg. one to two simulation time periods. Finally, the third decision point testing criteria is that working capital falls below $2000.00. Each of these criteria is checked every time increment of the simulation just as the current time is checked for equality with one of the time related regular decision points.

In the first simulation time increment following the completion of fall harvesting, subroutine INQUIR determines the requirements for each feed stock by using the current cohort populations and the current values of the time based feeding plans. This results in a value of $ACTED_{1n}(t)$--the total quantity of feed stock n required by feeding plans from the present through the end of the wintering season. $ACTED_{1n}(t)$ is determined in much the same way as $STKFED_n(t)$ is determined except that $ACTED_{1n}(t)$ is integrated over time in order to obtain the entire wintering requirements. This gives

$$ACTED_{1n}(t) = \int_{t_{fall}}^{FPLANS_{\ell-1}} \frac{1}{FQUAL_n(t)} * \left\{ \sum_{i=1}^{9} POP_i(t_{fall})*[CATTIN_{i1\ell-1}(t)* CNCFRC_{in}(t) + CATTIN_{i2\ell-1}(t)*RHGFRC_{in}(t)] \right\} dt$$

$$+ \int_{FPLANS_{\ell-1}}^{t_{spring}} \frac{1}{FQUAL_n(t)} \left\{ \sum_{i=1}^{9} POP_i(t_{fall})*[CATTIN_{i1\ell}(t)* CNCFRC_{in}(t) + CATTIN_{i2\ell}(t)*RHGFRC_{in}(t)] \right\} dt \tag{5.5.10}$$

where:

$ACTED_{1n}(t)$ = the season long requirements for feed stock n based on the present feeding rates and feed distribution planned

$CATTIN_{i1\ell}(t)$ = quantity of TDN fed to individual members of cohort i per day from concentrates under feed plan ℓ

$CATTIN_{i2\ell}(t)$ = quantity of TDN fed to individual members of cohort i per day from roughages under feed plan ℓ

$CNCFRC_{in}(t)$ = fraction of the concentrate allocation of TDN to cohort i derived from feed stock n

$= DISTFD_{in\ell}(t)$, if $LABELF_n = 1$

$= 0$, if $LABELF_n = 2$

$RHGFRC_{in}(t)$ = fraction of the roughage allocation of TDN to cohort i derived from feed stock n

$= DISTED_{in\ell}(t)$, if $LABELF_n = 2$

$= 0$, if $LABELF_n = 1$

$FQUAL_n(t)$ = fraction of TDN per kg feed for feed stock n

$POP(t_{fall})$ = the population of the ith herd cohort at t_{fall}

$FPLANS_\ell$ = time when the ℓth feed plan ends and the ℓ+1 plan begins

$$\ell = \begin{cases} 1, \text{ if } t < FPLANS_1 \\ 2, \text{ if } FPLANS_1 \leq t < FPLANS_2 \\ 3, \text{ if } FPLANS_2 \leq t < FPLANS_3 \\ 4, \text{ if } FPLANS_3 \leq t < FPLANS_4. \end{cases}$$

When the values of $ACTED_{1n}(t)$ have been computed, the following equation is the criteria used for deciding that a special decision point is needed to allow the user to adjust feed stock levels and planned feeding patterns to be compatible. A special decision point is required if

$$FTOL_1 < \left| \frac{FSTOCK_n(t_{fall}) - ACTED_{1n}(t_{fall})}{ACTED_{1n}(t_{fall})} \right| \qquad (5.5.11)$$

where:

$FTOL_1$ = fraction feed stocks can differ from the computed feed stock requirements implied by the feeding plans

$FSTOCK_n(t)$ = the current quantity for feed stock n on hand

$ACTED_{1n}(t)$ = feed stock n requirements of the present feed plans.

The second special decision point criteria is checked each time increment that feeding is taking place. A special decision point is required if

$$FINFLT*ACTED_{2n}(t) > FSTOCK_n(t) - STKLOS_n(t) \qquad (5.5.12)$$

where:

$ACTED_{2n}(t)$ = feed stock requirement for feeding cattle during the present time increment for feed stock n

$FSTOCK_n(t)$ = current quantity of feed stock n on hand

$STKLOS_n(t)$ = quantity of feed stock n lost through spoilage in the current increment of time

FINFLT = 2.0, factor by which the feed stock requirement of the current time increment is inflated as a safety margin.

$ACTED_{2n}(t)$ is determined in the same manner as is $STKFED_n(t)$ in subroutine CONSUM (described in section 4). Then,

$$ACTED_{2n}(t) = \frac{DAYS}{FQUAL_n(t)} * \sum_{i=1}^{9} POP_i(t)*\Big[CATTIN_{i1\ell}(t)*DISTFD_{in\ell}(t)*IN_1 + CATTIN_{i2\ell}(t)*DISTFD_{in\ell}(t)*IN_2\Big] \qquad (5.5.13)$$

where:

$ACTED_{2n}(t)$ = the quantity of feed stock n required by the current feeding plan for this time increment

$POP_i(t)$ = current population of cohort i

$FQUAL_n(t)$ = fraction of TDN per kg feed for feed stock n

$DISTFD_{in}(t)$ = fraction of the feed allocation to cohort i derived from feed stock n

$CATTIN_{i1}(t)$ = quantity of TDN allocated to cohort i from concentrates per day under feed plan ℓ

$CATTIN_{i2}(t)$ = quantity of TDN allocated to cohort i from roughages per day under feed plan ℓ

IN_1 = indicator of type of feed

= 1, if $LABELF_n = 1$

= 0, if $LABELF_n = 2$

IN_2 = an indicator of roughage feed

$$= \begin{cases} 1, \text{ if } LABELF_n = 2 \\ 0, \text{ if } LABELF_n = 1 \end{cases}$$

DAYS = number of days in a simulation time increment.

If the level of working capital falls below the arbitrary value of $2000, the model also signals a special decision point. This event is indicative that large cash outflows have drained the enterprise of working capital. A possible solution is short-term borrowing.

When any of these events signal a special decision point, the model follows the normal decision point procedure and awaits a restart with control variable values. Since the problem is not fully specified by events leading to a special decision point, the entire range of control variables is available to the user for inputting new values. Even if relatively little adjustment is made, the user is required to input all control variables; the values are left to user discretion.

The User's Guide to the Beef Cattle Enterprise Simulation Model specifies the exact format of the data cards containing control variable values required for each decision point. Figure 5.22 is a typical message printed by the computer at a decision point indicating the control variables which are required to restart the simulation.

Endogenous Decision Making

The management component model is constructed so that if none of the five decision points is encountered, then logical control shifts to subroutine NORMAL. This subroutine carries out all endogenous decision making within the component model. Four categories of decisions comprise the contents of this subroutine; these are:

```
EXOGENOUS INPUT REQUIREMENTS IN ORDER

     APFUTR(5,20)

     BPFUTR(8,10)

     CPFUTR(NSTOCK,10)

     PDSTRB(NLANDS,9)

     XCPROD(NSTOCK)

     XCQUAL(NSTOCK)

     CFINAL     REMOVL

     TBRD(1),TBRD(2),TWEAN,TCULL

     TMHR(5)

SEE THE USER GUIDE FOR INPUT FORMATS
```

Figure 5.22 Printed message at the spring growth decision point requesting values for specified control variables

1) timing of slaughter cohort cattle sales,

2) fall crop sales and purchases to obtain wintering feeding requirements,

3) mechanical harvesting of forage growth, and

4) concentrate and roughage cohort allocations.

These decisions are obviously more routine than those which must be made at each of the decision points. The criteria upon which some of these areas of endogenous decision making are based are standard economic ones; e.g., selling if the marginal cost of holding exceeds the marginal revenue. Some of the parameters used here are supplied at decision points for use over an extended time period.

Mechanical harvest of forage growth is an example of using exogenously supplied parameters over an extended period of simulated time. Three key variables are inputted into the model at the spring growth onset decision point; these are $TMHR_k$, REMOVL, and CFINAL. $TMHR_k$ specifies certain simulated times at which the forage growth then existing in various land parcels should be harvested. REMOVL specifies a fraction of the "excess" over and above current herd needs that is to be harvested at each of these harvest times. CFINAL specifies the fraction of the standing quantity of forage that is to be harvested at TFALL--the end of the growth season. $MHR_n(t)$ is the daily rate of forage removal from land parcel n. It is determined by:

$$MHR_n(t) = \begin{cases} 0, \text{ if } t \notin [TMHR_k, k=1, \ldots, 5] \\ 0, \text{ if } GRN_n t) < FLEVEL_n(t) \\ \frac{REMOVL}{DAYS} * [GRN_n(t) - FLEVEL_n(t)] \end{cases} \qquad (5.5.14)$$

where:

$GRN_n(t)$ = the quantity of forage material in land parcel n

DAYS = the number of days in the time increment DT

$$FLEVEL_n(t) = LOW*DAYS*\sum_{i=1}^{9} PDSTRB_{ni}(t)*POP_i(t) \qquad (5.5.15)$$

= a minimum quantity of forage needed to supply the animals grazing in land parcel n for one time increment

$PDSTRB_{ni}(t)$ = fraction of the population of cohort i grazing in land parcel n

LOW = 5.0, a minimum daily quantity of forage intake

$POP_i(t)$ = current population of cohort i.

When the end of the growth season arrives (t = TFALL), then the manager controls the final forage harvest through CFINAL.

$$MHR_n(t) = \frac{GRN_n(t)*CFINAL}{DAYS} \qquad (5.5.16)$$

where:

$MHR_n(t)$ = daily rate of mechanical harvest of forage from land parcel n

$GRN_n(t)$ = quantity of forage available in land parcel n

CFINAL = fraction of the forage in land parcel n to be harvested at the end of the growth season

DAYS = number of days in a simulation time increment.

Another end-of-growth-season activity is sales of the crop production that is produced by the enterprise. The predicted sales amounts have been determined at a breeding decision point; and if no extraordinary crop price changes have occurred that were not foreseen, then the predicted quantities are either sold or purchased. The resulting feed stock levels should be adequate to meet the desired

feeding rates that the manager has also specified at a breeding decision point.

$$CSALES_n(t) = -REACTD_n, \quad \text{if } REACTD_n < 0 \qquad (5.5.17)$$

$$STKPUR_n(t) = REACTD_n, \quad \text{if } REACTD_n > 0 \qquad (5.5.18)$$

where:

$CSALES_n(t)$ = quantity of feed stock n sold this period

$STKPUR_n(t)$ = quantity of feed stock n purchased this period

$REACTD_n$ = the predicted net purchases of feed stock n.

$REACTD_n$ is controlled by the user at the various decision points which are appropriate for such feed stock predictions.

An extremely important decision in a cattle enterprise is timing of animal sales. This decision is complicated by the reproductive implications of most sales; the uncertainties of the future market make decisions in this area quite complex. Two herd cohorts--steers and slaughter heifers--do not share this general difficulty. These cohorts have already been designated as sales animals only; the near term market condition and the weight gaining characteristics of these animals are the major considerations of the decision maker. The approach taken in this model is to determine whether or not the expected marginal revenue of retaining these cattle for one time increment exceeds the expected marginal costs. When net marginal revenue is positive no sales are made; the entire cohort population is sold when net marginal revenue is negative. A further check over a future interval of cattle prices is made before a decision to sell on the first criterion is actually carried out.

A key element in determination of expected marginal revenue is the weight gain expected from the input of feed to the animal. The method used here parallels the development of Schuette[48] in the nutrient impact subroutine NUTRN. The quantity and quality of feed fed to each slaughter cohort animal is the primary determinant of the weight gain of that animal. A constraint on cattle intake of feeds allocated is the capacity of the animal to consume the feed; this is modeled as a maximum fraction of the animal's body weight. Then

$$DMI_{ij}(t) = \min[\ a*W_{ij}(t)^{0.75},\ ALLOC_i(t)\ ] \qquad (5.5.19)$$

where:

$DMI_{ij}(t)$ = the daily consumption of feed of members of the jth subpopulation of cohort i (dry matter basis)

$W_{ij}(t)$ = weight of members of the jth subpopulation of cohort i

$$ALLOC_i(t) = \frac{CNCAL_i(t) + RHGAL_i(t)}{POP_i(t)*DAYS} \qquad (5.5.19a)$$

= the total allocation of feeds to members of herd cohort i

a = parameter based on the body weight of the cattle

$CNCAL_i(t)$ = concentrate allocation to cohort i -- kg/DT

$RHGAL_i(t)$ = roughage allocation to cohort i -- kg/DT

$POP_i(t)$ = population of cohort i

DAYS = number of days in a DT time increment.

Equation 5.5.19 has fixed the quantity of feed that is available for digestion by a member of a particular weight animal, while equation 5.5.20 determines the average TDN value of this quantity.

$$DMITDN_{ij}(t) = \frac{CNCAL_i(t)*TDNC_i(t) + [DMI_{ij}(t) - CNCAL_i(t)]*TDNR_i(t)}{DMI_{ij}(t)} \qquad (5.5.20)$$

where:

$DMITDN_{ij}(t)$ = the average TDN value of the feed consumed by a member of the jth subpopulation of cohort i

$TDNC_i(t)$ = average TDN value of the concentrate allocation to cohort i

$TDNR_i(t)$ = average TDN value of the roughage allocation to cohort i.

This equation assumes that the concentrates are consumed in their entirety before any roughages are consumed.

Once $DMITDN_{ij}(t)$ is determined it may be used as the basis for computing the energy values of the $DMI_{ij}(t)$ feed consumption for two purposes, i.e., energy used for maintenance of body processes and energy used for weight gains. EGAIN represents the energy value of the feed consumed in terms of mcal energy for gain/kg feed, while EMAIN represents the energy value of the feed consumed in terms of mcal energy for maintenance/kg feed. These values are determined from $DMITDN_{ij}(t)$ using subroutine CNVRT, which uses a method of conversion between these different systems of units authorized by the National Research Council.

The amount of energy used for weight gains is that which remains after the animal's maintenance requirements have been subtracted from its energy intake. Since there are two energy values per feed intake (one for body maintenance and one for weight gains) the determination of the energy available for weight gains must be determined from the quantity of feed used for maintenance purposes. This results in

$$EFORG_{ij}(t) = EGAIN*[DMI_{ij}(t) - 0.077*W_{ij}(t)^{0.75}/EMAIN] \qquad (5.5.21)$$

where:

$EFORG_{ij}(t)$ = energy available for weight gains for an animal in the jth subpopulation of cohort i -- mcal

EGAIN = gain energy value of the feed intake -- mcal/kg

EMAIN = maintenance energy value of the feed intake -- mcal/kg.

Having the value for $EFORG_{ij}(t)$ is the next to the last step for determining the actual rate of weight gain for animals in the jth subpopulation of cohort i. $DGAIN_{ij}(t)$ is computed by the following equation

$$DGAIN_{ij}(t) = \pm \frac{1}{d_i} \sqrt{a_i \pm \frac{b_i*EFORG_{ij}(t)}{W_{ij}(t)^{0.75}}} - c_i \qquad (5.5.22)$$

where:

$DGAIN_{ij}(t)$ = the rate of weight gain for members of the jth subpopulation of cohort i -- kg/day

a_i, b_i, c_i, d_i = constants for the ith herd cohort.

The upper signs are used when $EFORG_{ij}(t)$ is positive, and the lower signs are used when it is negative. This equation, then, gives positive weight gains for positive energy for gain values, and negative weight gains for negative energy for gain values.

Determination of the rate of weight gain that will result from the planned quantity and quality of feed allocation allows the marginal revenue of that weight gain to be calculated. This value is an expected revenue gained from feeding the animal to obtain the weight gain computed by equation 5.5.22.

$$FREV_i = \sum_{j=1}^{KK_i} DGAIN_{ij}(t)*DAYS*SUBPOP_{ij}(t)*XPECTA_k(t+dt) \qquad (5.5.23)$$

where:

$FREV_i$ = expected marginal revenue from the ith cohort -- \$

$DGAIN_{ij}(t)$ = the rate of weight gain for the animals in the jth subpopulation of cohort i -- kg/day

$SUBPOP_{ij}(t)$ = population of the jth subpopulalation of cohort i

$XPECTA_k(t+dt)$ = expected price of cattle of grade k at time t+dt -- \$/kg

$k = GRADE_{ij}(t)$ = price grade of animals within $SUBPOP_{ij}(t)$

KK_i = the number of subpopulation within cohort i

DAYS = the number of days in a DT time increment.

Once the expected marginal revenue of the weight gain has been determined the remaining factor is the marginal cost of the weight gain. Here, however, the marginal cost of maintaining the animal another DT time increment is more than just the cost of the feed used for weight gain. To be precise, the marginal cost is the cost of all of the feed fed to the animal, the costs of delivery of that feed, and any other costs associated with retaining the animal. The model for marginal costs used here breaks costs down into two factors, cost of the feed allocated, and cost of delivery of that feed. Other factors are assumed to be negligible in comparison to these two factors.

$$FCOST_{i,feed} = POP_i(t)*DAYS*\sum_{n=1}^{NSTOCK} \frac{CPRICE_n(t)}{FQUAL_n(t)}*[\ CATTIN_{i1\ell}(t)*CNCFRC_{in}(t) + CATTIN_{i2\ell}(t)*RHGFRC_{in}(t)\ ] \qquad (5.5.24a)$$

where:

$FCOST_{i,feed}$ = the cost of the feed stocks fed to members of cohort i in the current time increment -- \$

$CPRICE_n(t)$ = current price of feed stock n -- \$/kg

$CATTIN_{i1\ell}(t)$ = allocation of TDN from concentrates per animal per day to members of cohort i under feeding plan ℓ -- kg TDN/day

$CATTIN_{i2\ell}(t)$ = allocation of TDN from roughages per animal per day to members of cohort i under feeding plan ℓ -- kg TDN/day

$CNCFRC_{in}(t)$ = $DISTFD_{in\ell}(t)$, proportion of the feed from concentrates delivered to cohort i derived from feed stock n

$RHGFRC_{in}(t)$ = $DISTFD_{in\ell}(t)$, proportion of the feed from roughages delivered to cohort i derived from feed stock n

$FQUAL_n(t)$ = the average TDN value of the nth feed stock.

The cost of feeding these quantities of feeds is given by

$$FCOST_{i,feeding} = [\ CNCAL_i(t) + FEEDAL_i(t)\ ]*HRFED1*BPRICE_1(t) \quad (5.5.24b)$$

where:

$FCOST_{i,feeding}$ = cost of feeding cohort i for one DT time increment from labor use -- $

$CNCAL_i(t)$ = quantity of concentrates fed to cohort i -- kg/DT

$RHGAL_i(t)$ = quantity of roughages fed to cohort i -- kg/DT

HRFED1 = hours of labor for feeding cattle -- hours/kg

$BPRICE_1(t)$ = cost of labor -- $/hour.

The total marginal cost of retaining the ith cohort of the herd for another DT time increment is then the summation of the two factors explained above--the feed itself and the labor to feed it. Then

$$FCOST_i = FCOST_{i,feed} + FCOST_{i,feeding} \quad (5.5.24c)$$

where:

$FCOST_i$ = the total marginal costs of retaining cohort i for another DT time increment -- $.

When the expected marginal revenue is discounted appropriately, and then still exceeds the expected marginal costs, then no members of the cohort will be sold in the current time increment. Discounting the expected marginal revenue reflects the uncertainty that exists in the future cattle price values. If marginal revenue happens to be smaller than marginal costs, then expected cattle prices are searched over some interval into the future in an attempt to discover the highest price within this time interval. The period of time into the future searched by subroutine NORMAL is a control variable set by the model user. If the highest value of cattle prices within the interval

[t, t+RANGE) falls within the interval [t, t+dt) then the entire cohort population should be sold. The revenue gained from sales will be highest if the animals are sold immediately, rather than retaining them for the future. The control variable $ADDRT_i(t)$ is used to carry out this sales action; therefore

$$ADDRT_i(t) = \frac{-POP_i(t)*(1 - DR_i*DT)}{DT} \tag{5.5.25}$$

where:

$POP_i(t)$ = population of cohort i

DR_i = death rate of cohort i in fraction per year

$ADDRT_i(t)$ = annual rate of additions of animals to cohort i -- animals/year

DT = the basic simulation time increment -- years.

If the highest price occurs at a time exceeding t + dt then no sales are made in this period, because more revenue can be gained by waiting for this higher price before selling.

The endogenous decision mechanism for selling the slaughter cohorts has utilized the idea of marginal net revenue to guide the decision to sell or to retain animals. When marginal revenue (net) is positive then the proper decision should be retention of the cattle since the costs of holding are exceeded by the anticipated revenue of holding. Alternatively, when marginal net revenue is negative, the proper decision is to sell immediately. This mechanism is a straightforward application of standard economic theory.

The last area that is included in this model of endogenous decision making is the allocation of feed stocks to the herd cohorts. This also includes the distribution of the allocation among specific feed

stocks using the control variables $CNCFRC_{in}(t)$ and $RHGFRC_{in}(t)$. Feed stocks are allocated to the herd under two separate circumstances: during the wintering period and during the growing season if the quantity or quality of forage falls too low. The alternative feeding plans used by the manager of this enterprise are modeled using the variables FPLANS, $CATTIN_{ik}(t)$, and $DISTFD_{in}(t)$; these are the times when feeding plans change, the quantity of TDN allocated to members of herd cohorts per day, and the distribution of the TDN allocation among feed stocks, respectively. The allocations of concentrate and roughage to each cohort is determined by the allocation to each animal, the distribution of the allocation among the feed stocks, and the TDN value of each feed stock. This results in

$$CNCAL_i(t) = \left\{ \sum_{n=1}^{NSTOCK} CNCFRC_{in}(t)/FQUAL_n(t) \right\} *CATTIN_{i1\ell}(t)*POP_i(t)*DAYS \tag{5.5.26}$$

$$FEEDAL_i(t) = \left\{ \sum_{n=1}^{NSTOCK} RHGFRC_{in}(t)/FQUAL_n(t) \right\} *CATTIN_{i2\ell}(t)*POP_i(t)*DAYS \tag{5.5.27}$$

where:

$CNCAL_i(t)$ = the quantity of concentrates allocated to cohort i for one DT time increment--kg conc./DT

$FEEDAL_i(t)$ = the quantity of roughages allocated to cohort i for one DT time increment--kg/DT

$CATTIN_{i1\ell}(t)$ = allocation of TDN from concentrates per day to members of cohort i under feed plan ℓ

$CATTIN_{i2\ell}(t)$ = allocation of TDN from roughages per day to members of cohort i under feed plan ℓ

$POP_i(t)$ = current population of cohort i

DAYS = the number of days in a DT time increment

$FQUAL_n(t)$ = the current average TDN value of feed stock n

$$CNCFRC_{in}(t) = \begin{cases} DISTFD_{in\ell}(t), \text{ if } LABELF_n = 1 \\ 0, \text{ if } LABELF_n = 2 \end{cases}$$

$$RHGFRC_{in}(t) = \begin{cases} DISTFD_{in\ell}(t), \text{ if } LABELF_n = 2 \\ 0, \text{ if } LABELF_n = 1 \end{cases}$$

$$\ell = \begin{cases} 1, \text{ if } 0 \leq t < FPLANS_1(t) \\ 2, \text{ if } FPLANS_1(t) \leq t < FPLANS_2(t) \\ 3, \text{ if } FPLANS_2(t) \leq t < FPLANS_3(t) \\ 4, \text{ if } FPLANS_3(t) \leq t < FPLANS_4(t) \end{cases}$$

The nutrient impact component subroutine CONSUM uses the variables $CNCAL_i(t)$, $CATTIN_{i1\ell}(t)$, $FEEDAL_i(t)$, $CATTIN_{i2\ell}(t)$, and $RHGFRC_{in}(t)$ to determine the average TDN value of concentrates, $TDNC_i(t)$, and of roughages, $TDNR_i(t)$. This is more fully explained in section V.4.

During the grazing season there may be instances where supplementary feeding is necessary to provide nutrients that grazing alone cannot deliver. Drought, with extremely low growth rates or none at all, is an example. Subroutine NORMAL checks for such conditions by determining the quantity and quality of forage available. Normally the feed allocations to all cohorts are zero; i.e., $CNCAL_i(t)$ = $FEEDAL_i(t)$ = 0.0, i=1, ..., 9. A minimum herd feeding rate, RGRAZE(t), is computed to compare against forage stocks, with

$$RGRAZE(t) = MIN*DAYS* \sum_{n=1}^{NLANDS} STOCKL_n(t)*LAND_n \qquad (5.5.28)$$

where:

RGRAZE(t) = a minimum quantity of forage necessary to sustain the grazing herd over one DT time increment--kg/DT

$STOCKL_n(t)$ = the stocking rate in land parcel n--#/hec

$LAND_n$ = area of land parcel n--hectares

MIN = a minimum daily ration of forage per animal--kg/day

DAYS = the number of days in a DT time increment.

The quantity of forage available, TGREEN(t), and the associated average TDN value of that forage, VGREEN(t), are given by

$$TGREEN(t) = \sum_{n=1}^{NLANDS} GRN_n(t) \qquad (5.5.29)$$

$$VGREEN(t) = \left[\frac{1}{TGREEN(t)}\right] * \sum_{n=1}^{NLANDS} GRN_n(t)*DIGEST_n(t) \qquad (5.5.30)$$

where:

$GRN_n(t)$ = quantity of forage in land parcel n

$DIGEST_n(t)$ = quality of forage in land parcel n.

If TGREEN $\geq$ RGRAZE(t) and VGREEN(t) $\geq$ 0.40 then no supplemental allocation is made; otherwise, the following roughage allocation is made

$$FEEDAL_i(t) = RAL*DAYS*POP_i(t),\ i=1,\ \ldots,\ 9 \qquad (5.5.31)$$

where:

$FEEDAL_i(t)$ = quantity of roughage allocated to herd cohort i--kg/DT

$POP_i(t)$ = current population of cohort i

RAL = 5.0, a minimal supplementary feeding level to assist an individual animal--kg/day.

The entire allocation of supplement must come from stored forage retained from the previous wintering season, or perhaps from forage already harvested and stored this growth season. $RHGFRC_{i1}(t) = 1.0$ for all herd cohorts.

Summary

The management decision making component model has been constructed to meet the requirements specified in the problem statement (Chapter III). Because the complexity of many decisions makes them extremely difficult to reduce to computationally solvable forms, the model has been developed to seek some control values exogenously. Such decisions have been termed decision points and usually are associated with specific herd actions; e.g., breeding, weaning, culling, and starting grazing. Some less complex decisions can be determined endogenously within the model using standard economic criteria. Examples are the decision to sell slaughter cohort animals, forage harvesting, and feed allocations to the herd. The mechanical process of seeking exogenous values for some control variables involves using the simulation model interactively in a batch mode. The user studies the simulation record over time and the specific information printed at each decision point to provide a basis for action. Evaluation of multiple decision strategies at a particular decision point is possible through the use of permanent files which "freeze" the simulation as it is at a decision point. The user can review the results at his leisure and then continue the simulation by simply attaching the appropriate permanent file once he has made his selection. This feature makes exploration of intuitive feelings and alternative exogenous variable assumptions quite feasible.

The decision making component has been developed to be realistic in its treatment of actions taken by operating managers of ranchs.

The fine level of control variables makes many different types of strategy evaluation possible. Annual decision patterns, such as culling and weaning, can be investigated, as can investment planning projects. In short, the decision making component has been constructed to be as flexible as possible in meeting the potential desires of managers interested in evaluating the consequences of alternative decisions.

V.6 Secondary Component Models

Chapter IV, section 2, provided a brief introduction to the three secondary components of this system; these are exogenous variable determination, management of expected prices, and enterprise financial accounting. This section will review the purpose and detailed construction of each of these components' model.

Exogenous Variable Component

The simulation model has three types of exogenous variables which influence the physical variables and management decision making. These are crop and animal prices, climatic factors--temperature, solar radiation, and rainfall, and feed crop production. Although a totally comprehensive model of a beef cattle enterprise would endogenously determine the crops to be planted as a function of prices and available resources, this modeling effort is restricted to exogenous specification of feed crop production. A year long stream of crop production is specified with uniform spacing of values. This process is illustrated graphically in Figure 5.23. The subroutine EXOG determines crop production for each possible feed crop in the interval (t - dt/2, t + dt/2) by comparing the current simulated time T to the specified harvest time of each crop. The effect of this structure is an impulse whose height is the amount harvested in the interval. $CROP_{n1}(t)$ is the variable name used for this quantity harvested in the time interval. $CROPQL_{n1}(t)$ gives the TDN value of this quantity, $CROP_{n2}(t)$ specifies the quantity of crop n residue that is harvested, while $CROPQL_{n2}(t)$ gives the TDN value of that residue.

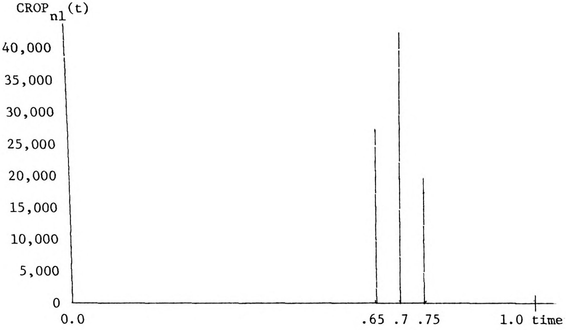

Figure 5.23 Yearly pattern of crop harvest as exogenously specified

Current prices and the current weather variables are also determined by subroutine EXOG. These are treated somewhat differently than crop production because both prices and weather are continuous variables, while crop production is not. Instead of searching the input values for a match between current time and some specified time point to get an associated data value, prices and the weather variables are determined through linear interpolation to compute the proper value. The utility function TABLIE[1] is used to accomplish this interpolation. Figure 5.24 shows how this procedure works for the weather variable RAIN(t). The following exogenous variables are determined in similarily: SOLAR(t), AVGTMP(t), $APRICE_k(t)$, k=1,...,5 and $CPRICE_n(t)$, n=1,...,NSTOCK.

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1. Llewellyn, R.,FORDYN: A Industrial Dynamics Simulator, privately published, Raleigh, N. C., 1965, p. 4-20.

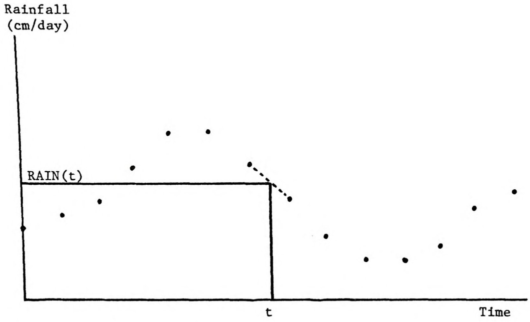

Figure 5.24 Linear interpolation between exogenously specified annual rainfall data points to obtain the current rainfall value

Currently the model assumes that the weather and crop variables are spaced uniformly with an interval of 0.05 years between values. Further, the model assumes that the weather variables are repeated year after year with no change. This assumption requires that one view the weather variables as long run averages rather than specific values from a stochastic process. A change in the component model to actually use stochastic processes to represent the three weather variables would be quite simple, but since at this time the entire model uses deterministic variables rather than stochastic ones, this change will not be made. Other spacings between the specified annual pattern would also be quite easy to implement, even non-uniform ones.

Expected Prices Component

Expected prices are an important base for the decision making of the enterprise manager. These prices are also characterized by their volatility as the agricultural sector of the economy; and the beef cattle industry, in particular, reacts to economic and political events throughout the world. The subroutine RESPNS has provisions for reading in up to two years' expected prices for cattle and up to one year's expected prices for crops at each decision point.

During routine operation of the overall model as it simulates the passage of time, subroutine GENERT acts to make available the proper stream of future expected prices from the current point in time. Recall that at each decision point the model user is asked to respecify the stream of prices for the feed stocks and for all five cattle slaughter grades through the future. The array $CPFUTR_n(t)$ holds the stream of future prices for feed stock n spaced in intervals of 2DT's from the present, t_0, through simulated time t_0 + 20DT's. The array $APFUTR_k(t)$ holds the stream of future prices for cattle grade k spaced in intervals of 2DT's from the present, t_0, through simulated time t_0 + ODT's. In an effort to make this specified set of prices available to the model as simulated time progresses forward from the time at which the values were specified, GENERT advances the entries in the arrays $CPFUTR_n(t)$ and $APFUTR_k(t)$ on alternate DT increments of simulated time. Figure 5.25 provides an example of this procedure using the variable $APFUTR_3(t)$. In Figure 5.25a the points specify the expectations of prices for cattle of grade 3 for a time span of 24DTs. The labelled points p_1, p_2, p_3 specify grade 3 cattle prices at times

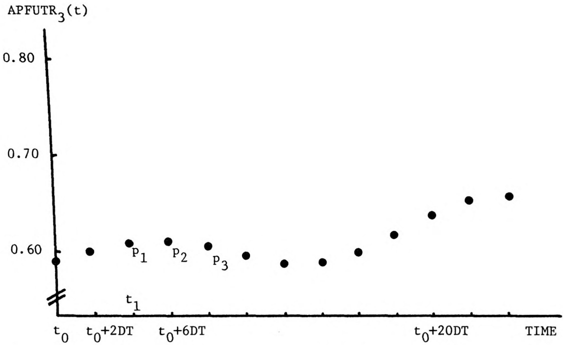

Figure 5.25a Expected cattle prices over time starting from t_0

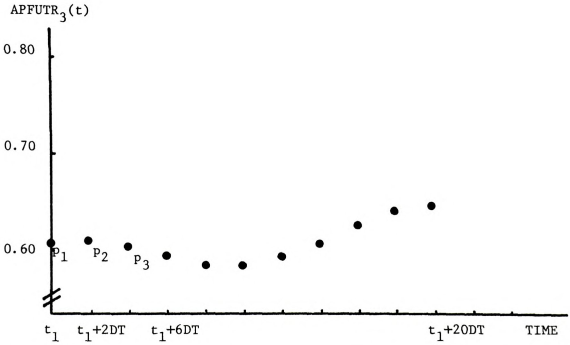

Figure 5.25b Expected cattle prices over time starting from t_1

$t_0 + 4DT$, $t_0 + 6DT$, and $t_0 + 8DT$, respectively. The point t_0 represents the current value of simulated time while p_1, p_2, and p_3 are specified distances of time into the future (from the point of view of simulated time). When simulated time advances as the simulation proceeds, the stream of points needs to be shifted to the left to bring the proper value of expected price into correlation with the present value of simulated time. Lets suppose that simulated time has advanced 4DTs from t_0; this is the value t_1. Figure 5.25b depicts the proper positioning of value of $APFUTR_3(t)$ with t_1 being the present simulated time. The curve given by data points in Figure 5.24a has been shifted 4DTs to the left as it should to preserve the relationship between p_1, p_2, and p_3. Notice that the price values p_2 and p_3 are still the proper 2DTs and 4DTs into the future of simulated time from t_1 in Figure 5.24a as they were in Figure 5.24a. Subroutine GENERT maintains this price positioning for all five cattle price grades, and for all NSTOCK feed stock prices.

Subroutine CBOX[23] is used in subroutine GENERT to perform this shifting of price array entries on alternate DT time increments. CBOX also cycles the price value being removed to the furthest most array location meaning that a price cycle of duration 40DTs is assumed for cattle prices, and a price cycle of 20DTs is assumed for feed stock prices. Of course the model user has the opportunity to respecify the entire stream of prices at each decision point, so the price cycle assumption implied by using CBOX is quite weak.

The major reason for this complex movement of price values as simulated time advances is the ease with which current prices and future expected prices from the current time may be determined. The three

functions XPECTA(k,T), XPECTB(1,T), and XPECTC(n,T) are used to determine the expected price at time T for grade k cattle, resource 1, and feed stock n, respectively. Each of these function subprograms are designed to linearly interpolate between array entries to determine the correct price at any desired time point within the range of times for which price expectations are valid. Current prices are determined from these function subprograms by using the current time as the argument of the function; this gives $APRICE_k(t)$ = XPECTA(k,t), $BPRICE_1(t)$ = XPECTB(1,t), and $CPRICE_n(t)$ = XPECTC(n,t). The function subprogram TABLIE(from Llewelyn) is used within each of the expectation functions to perform the linear interpolation required.

Financial Accounting Component

This component performs two tasks: first, accounting for all purchases, sales, repayments, and taxes which occur during simulated time; and second, computing present values of certain variables at the end of a multiyear simulation run. Subroutine FINANC is the main element of this component, others are subroutines REVENU, PRCOST, CAPTAL and TAXSUB. The name of each of these subroutines is illustrative of the function it performs. This component will be explained in terms of four types of variables: revenues earned, costs incurred, interest on debt and debt repayment, and taxes.

Subroutine REVENU determines the revenue earned from sales of cattle and crops. Physical amounts sold times the market price equals the revenue incoming to the enterprise. Because crops are assumed to be homogeneous, crop revenues are much easier to determine than cattle revenue.

Then

$$CREV_n(t) = CPRICE_n(t)*CSALES_n(t) \tag{5.6.1}$$

where:

$CREV_n(t)$ = revenue from sales of crop n -- $/DT

$CPRICE_n(t)$ = market price of crop n -- $/kg

$CSALES_n(t)$ = quantity of crop n sold -- kg/DT.

Total crop revenue is the summation of each crop's revenue giving

$$CREV_{NCROPS+1}(t) = \sum_{n=1}^{NCROPS} CREV_n(t) \tag{5.6.2}$$

where:

$CREV_{NCROPS+1}(t)$ = total crop revenue earned in this time increment--$/DT

$CREV_n(t)$ = crop revenue earned from sales of crop n in this time increment--$/DT

NCROPS = the total number of possible crops.

Determination of cattle revenue is complicated by the fact that not all sales animals have the same weight or the same price grade. Quantities of cattle sold from each of the nine herd cohorts are given by two variables, $ROUT_i(t)$ and $ADDRT_i(t)$ represents the annual output rate of cohort i, while $ADDRT_i(t)$ represents the annual rate of additions to the herd (which can be either positive or negative). When $ADDRT_i(t) < 0$, then there is a negative addition to the cohort; i.e., sales. These additions are assumed to affect each cohort subpopulation as a uniform percentage of its current subpopulation. Section 1 explains this process more completely. Certainly not all of the animals leaving cohort i are sold--some are only being transferred from one cohort to another. An example is the output from the replacement heifer cohort; here virtually all of the output is being transferred to the mature cow cohort and not being sold.

Figure 5.3 illustrated the structure of the herd demographic model and the use of the control variables C2, C3, C4, C5, C6, C9, C10, and C to direct the flows of cattle leaving each cohort. The variable $CON_i(t)$ represents the proportion of the output flow rate, $ROUT_i(t)$, that is sold. Study of Figure 5.3 will show that

$$CON_1(t) = 1.0 \qquad (5.6.3)$$

$$CON_2(t) = 1.0 - C10$$

$$CON_3(t) = C11$$

$$CON_4(t) = 1.0$$

$$CON_5(t) = C6$$

$$CON_6(t) = 1.0$$

$$CON_7(t) = C4$$

$$CON_8(t) = C9$$

$$CON_9(t) = 1.0$$

Combining the sales resulting from negative "cohort additions," and exits from the herd due to satisfaction of individual cohort delay times, gives the total animal sales in the current time increment as

$$ASALES_i(t) = DT*[ROUT_i(t)*CON_i(t) + U_i(t)] \qquad (5.6.4)$$

where:

$ASALES_i(t)$ = number of animals sold from cohort i in this time period--#/DT

DT = length of the simulation time increment in years

$ROUT_i(t)$ = cohort i delay output rate--#/year

$CON_i(t)$ = proportion of i^{th} cohort output rate sold

$U_i(t) = 0$, if $ADDRT_i(t) \geq 0$

$= -ADDRT_i(t)$, if $ADDRT_i(t) < 0$

$ADDRT_i(t)$ = annual rate of additions to cohort i--#/year.

Since cattle prices are in terms of \$/kg, the above expression is not yet sufficient for determination of revenue. The weight of each of the cohort sale quantities must yet be determined. Additionally, there are five cattle price grades; this requires that the average grade for each cohort's sale animals also be determined. The variables $AVGW_i(t)$ and $AVGGRD_i(t)$ specify the average cohort sales weight and average price grade, respectively.

$$AVGW_i(t) = \frac{DT*ROUT_i(t)*CON_i(t)*W_{i,KK_i}(t)}{ASALES_i(t)} + \frac{[ASALES_i(t) - DT*ROUT_i(t)*CON_i(t)]*ALWT_i(t)}{ASALES_i(t)} \qquad (5.6.5)$$

where:

$W_{ij}(t)$ = the average weight of cattle in the j^{th} subpopulation of cohort i

$ALWT_i(t)$ = the average weight of the ith herd cohort -- kg/animal

$$= \sum_{j=1}^{KK_i} \frac{W_{ij}(t)*SUBPOP_{ij}(t)}{POP_i(t)} \qquad (5.6.5a)$$

where:

KK_i = the number of stages in the delay model of cohort i

$SUBPOP_{ij}(t)$ = number of animals in the j^{th} subpopulation of cohort i

$POP_i(t)$ = total population of cohort i.

The average grade of cattle sold from cohort i is

$$AVGGRD_i(t) = \frac{DT*ROUT_i(t)*CON_i(t)*GRADE_{i,KK_i}(t)}{ASALES_i(t)} + \frac{[ASALES_i(t) - DT*ROUT_i(t)*CON_i(t)]*ALGD_i(t)}{ASALES_i(t)} \qquad (5.6.6)$$

where:

$GRADE_{ij}(t)$ = the price grade of animals in the j^{th} subpopulation of cohort i

$ALGD_i(t)$ = the average grade of animals in cohort i

$$= \sum_{j=1}^{KK_i} \frac{GRADE_{ij}(t)*SUBPOP_{ij}(t)}{POP_{ij}(t)} \quad (5.6.6a)$$

$ROUT_i(t)$ = the output rate of the i^{th} cohort delay model--#/year

$ASALES_i(t)$ = the number of cattle from cohort i sold in this time period--#/DT

$CON_i(t)$ = the fraction of the output rate of cohort i sold

$SUBPOP_{ij}(t)$ = the population of the j^{th} subpopulation of cohort i

$POP_i(t)$ = population of cohort i

DT = the time increment of the simulation--fraction of a year.

$AVGGRD_i(t)$ is further constrained to be an integer, since there are specific price grades, not a continuum of prices based on slight physical differences. The revenue earned from cattle sales, $AREV_i(t)$, is then

$$AREV_i(t) = ASALES_i(t)*AVGW_i(t)*APRICE_{AVGGRD_i(t)}(t) \quad (5.6.7)$$

where:

$AREV_i(t)$ = revenue earned from sales of cattle from cohort i in the current time increment--\$/DT

$ASALES_i(t)$ = the number of animals sold from cohort i in the current time period--#/DT

$AVGW_i(t)$ = the average weight of cattle sold from cohort i--kg

$APRICE_k(t)$ = the current price for cattle of grade k--\$/kg

$AVGGRD_i(t)$ = the average price grade of cattle sold from cohort i in this time increment.

The total revenue earned from cattle sales in the current time period is the summation of the revenue earned from sales in each cohort, giving

$$AREV_{10}(t) = \sum_{i=1}^{9} AREV_i(t) \tag{5.6.8}$$

where:

$AREV_{10}(t)$ = total revenue earned from sales of cattle in this time increment -- \$/DT

$AREV_i(t)$ = revenue earned from sales of cattle from cohort i in this time increment -- \$/DT.

Subroutine PRCOST determines the costs of production for cattle and for crops. Cattle production costs are determined by valuation of the quantities of eight production resources used for various activities associated with the cattle herd. Examples of such activities are breeding, weaning, culling, feeding the herd, etc. Nine categories of production cost are used to allow realism in this model. A list of the nine categories of cattle production cost along with the variable name and the units used is given in Table 5.1. Crop production costs are determined in a much less rigorous manner since crop production is not modeled as such in this simulation model. Crop production costs are basically determined by assuming that the cost of production to the enterprise is a fixed proportion of the market price at harvest time. This costing mechanism is recognized as being unrealistic, but it is tolerable here because of the place crop production assumes in the overall priority of this project. $ACOST_k(t)$ and $CCOST_k(t)$ are the variables which are used to represent specific categories of cost for cattle and crops, respectively. Table 5.1 defines these variables.

Table 5.1 Definition of Crop and Cattle Expense Variables

Variable	Definition	Units
$ACOST_1(t)$	Labor expenses	\$/DT
$ACOST_2(t)$	Repair expenses	\$/DT
$ACOST_3(t)$	Utility expenses	\$/DT
$ACOST_4(t)$	Veterinary and breeding expenses	\$/DT
$ACOST_5(t)$	Fertilizer and seed expenses	\$/DT
$ACOST_6(t)$	Leased land expenses	\$/DT
$ACOST_7(t)$	Animal feeding expenses	\$/DT
$ACOST_8(t)$	Cattle purchase costs	\$/DT
$ACOST_9(t)$	Miscellaneous, overhead, etc.	\$/DT
$CCOST_1(t)$	Feed crop production expenses	\$/DT
$CCOST_2(t)$	Mechanical harvesting of forage costs	\$/DT
$CCOST_3(t)$	Feed stock purchase expenses	\$/DT

Crop costs are determined directly from crop production and feed stock purchases. Since all crops except forage are exogenously specified by the user, determination of costs is quite difficult. The method used here is to simply deflate the current market price to get a hypothetical production cost. Then

$$CCOST_1(t) = \sum_{n=2}^{NSTOCK} CROP_{n1}(t)*CPRICE_n(t)*DEFLAT \qquad (5.6.9)$$

$$CCOST_2(t) = DAYS*\left(\sum_{n=1}^{NLANDS} MHR_n(t)\right)*[HRHARV*BPRICE_1(t) + SPHARV*BPRICE_3(t)] \qquad (5.6.10)$$

where:

$CCOST_1(t)$ = production of the current feed crop costs

$CCOST_2(t)$ = current costs of harvesting forage

$CROP_{n1}(t)$ = current production of crop n -- kg/DT

$BPRICE_1(t)$ = current price per unit of production resource 1

HRHARV = hours of labor per kg forage harvested

SPHARV = units of utilities required to harvest forage -- units/kg

$MHR_n(t)$ = daily rate of forage harvest from land parcel n

DAYS = number of days in a DT time increment

$CPRICE_n(t)$ = current market price of feed stock n -- $/kg

DEFLAT = scaling factor to determine crop production costs in terms of current price.

Costs of crop purchases are simply the summation of the quantities purchased times their current price, giving

$$CCOST_3(t) = \sum_{n=1}^{NSTOCK} STKPUR_n(t)*CPRICE_n(t) \qquad (5.6.11)$$

where:

$STKPUR_n(t)$ = quantity of crop n purchased this time period

$CCOST_3(t)$ = cost of feed stock purchases in the current period

$CPRICE_n(t)$ = current price of crop n--\$/kg.

Total crop costs in this period (feed stock costs) is the summation of each of these individual cost factors; $CCOST_2(t)$ is excluded from this summation because the forage production costs will be added into the animal production costing. This is done simply to keep all animal-related factors together.

$$CCOST_4(t) = CCOST_1(t) + CCOST_3(t) \tag{5.6.11a}$$

where:

$CCOST_4(t)$ = the total crop-related production costs in this time period.

Table 5.2 Definition of Resource Variables

VARIABLE	DEFINITION
$RESORC_1(t)$	Hours of labor
$RESORC_2(t)$	Units of veterinary supplies
$RESORC_3(t)$	Units of utilities
$RESORC_4(t)$	Kgs of fertilizer
$RESORC_5(t)$	Kgs of seed
$RESORC_6(t)$	Hectares of land leased
$RESORC_7(t)$	Units of breeding supplies
$RESORC_8(t)$	Units of repair materials

The quantities of each resource variable, $RESORC_1(t)$, used in each time increment of the simulation are a function of the different events and activities which have taken place within that DT time period. To write conventional equations listing the total amount of each resource used would require as many equation sets as there are combinations of events and activities. To avoid this difficult task, the quantity of resources required for each event or activity will be defined separately for each event or activity which exists. The total quantity of each of the eight resources used in any particular DT time increment is determined by the particular set of events which has occurred within that time increment. This means that the sense of each of the equations used here is

$RESORC_1(t) = RESORC_1(t)$ + a specific event-related amount.

In the simulation model this organization is quite natural because of the ease with which IF statements can be used to shunt the logical path of flow through series of equations which apply only for specific events or specific times of the year. When an equation of form 5.6.12 through 5.6.25 is encountered, the quantity calculated is simply added to whatever sum already existed for that variable. The only requirement needed to perform this addition is initialization of resource quantity used to zero at the beginning of each DT increment of the simulation.

Feeding is a major activity requiring the use of resources, primarily labor. The amount of labor used for feeding is

$$RESORC_1(t) = HRFED1 * \sum_{n=1}^{NSTOCK} STKFED_n(t) \qquad (5.6.12)$$

where:

$RESORC_1(t)$ = hours of labor required to feed cattle this time increment--hr/DT

$STKFED_n(t)$ = quantity of feed stock n fed to cattle--kg/DT

$HRFED1$ = hours of labor per kg of feed stocks fed.

Another major source of production costs is breeding, especially if artificial insemination is used. This activity requires labor as well as breeding supplied. Furthermore, breeding is not a single event but an activity covering an extended period of time; i.e., $DURB_i(t)$ for the i^{th} cohort. The number of hours of labor required for breeding is modelled as a function of the number of servicings experienced by each herd cohort subpopulation. The variables DT and $DURB_i(t)$ act to spread the quantity of labor hours required uniformly over the interval $DURB_i(t)$, i=1, ..., 3. They act similarly in spreading breeding supply resources used uniformly as well.

$$RESORC_1(t) = HRBRED * \sum_{i=1}^{3} \sum_{j=1}^{KK_i} \frac{INB_{ij}(t) * SUBPOP_{ij}(t) * DT}{DURB_i(t)} \qquad (5.6.13a)$$

$$RESORC_7(t) = SPBRED * \sum_{i=1}^{3} \sum_{j=1}^{KK_i} \frac{INB_{ij}(t) * SUBPOP_{ij}(t) * DT}{DURB_i(t)} \qquad (5.6.13b)$$

where:

$RESORC_1(t)$ = hours of labor used for breeding in this time increment--hours/DT

$RESORC_7(t)$ = units of breeding supplies used for breeding in this time increment--units/DT

$INB_{ij}(t)$ = number of breedings for the j^{th} subpopulation of cohort i

$DURB_i(t)$ = duration of cohort i breeding

HRBRED = hours of labor required per servicing

SPBRED = number of units of breeding supplied per servicing

$SUBPOP_{ij}(t)$ = number of cattle in the j^{th} subpopulation of cohort i.

Calving costs are modeled as using labor exclusively; equation 5.6.14 determines the number of hours of labor used in a DT time increment by summing the number of newly born male and female calves and multiplying by the labor resource parameter HRCALV. Then

$$RESORC_1(t) = HRCALV*[SUBPOP_{71}(t) + SUBPOP_{81}(t)] \quad (5.6.14)$$

where:

$RESORC_1(t)$ = hours of labor required for calving assistance in the current time period

$SUBPOP_{71}(t)$ = number of newly born male calves

$SUBPOP_{81}(t)$ = number of newly born female calves

HRCALV = hours of labor required per calf born.

When calves reach a specified age, all calves are vaccinated and most male calves are castrated. These events are modeled as using labor and vaccination supplies, giving

$$RESORC_1(t) = HRCAST*(1 - C2)*POP_7(t) + HRVACC*[POP_7(t) + POP_8(t)] \quad (5.6.15)$$

$$RESORC_2(t) = SPVACC*[POP_7(t) + POP_8(t)] \quad (5.6.16)$$

where:

$RESORC_1(t)$ = hours of labor required in the current DT time increment to perform castration of male calves and vaccination of both male and female calves--hours/DT

$RESORC_2(t)$ = units of veterinary supplies used for vaccination in this DT time increment--#/DT

SPVACC = quantity of veterinary supplies used per calf vaccinated

$POP_i(t)$ = total population of the i^{th} cattle cohort

C2 = fraction of male calves cohort output being retained for bull replacement

HRCAST = hours of labor per calf castrated

HRVACC = hours of labor per calf vaccinated.

Weaning and culling are herd management activities which only require labor. Weaning labor requirements are:

$$RESORC_1(t) = HRWEAN*\left\{\sum_{j=IAMIN}^{KK_7} SUPBOP_{7j}(t) + \sum_{j=IAMIN}^{KK_8} SUBPOP_{8j}(t)\right\} \qquad (5.6.17)$$

where:

$RESORC_1(t)$ = the number of hours of labor required to wean calves and transfer them to desired uses--hours/DT

$SUBPOP_{7j}(t)$ = population of the j^{th} subgroup of male calves

$SUBPOP_{8j}(t)$ = population of the j^{th} subgroup of female calves

KK_i = the number of subpopulations of the i^{th} herd cohort

HRWEAN = number of hours of labor required per calf weaned--hr/calf

IAMIN = the subpopulation index of the calf cohorts which is the smallest index greater than the age represented by AGEMIN.

Culling is another herd management procedure which can be modeled as utilizing labor resources exclusively. The quantity of labor required for culling is directly proportional to the number of cows culled; this gives

$$RESORC_1(t) = HRCULL*\sum_{j=1}^{KK_1} SUBPOP_{1j}(t)*CULFRC_j(t) \qquad (5.6.17a)$$

where:

$RESORC_1(t)$ = the number of hours of labor required for culling of the mature cow herd

$SUBPOP_{1j}(t)$ = the number of cows in the j^{th} subpopulation of the mature cow cohort

$CULFRC_j(t)$ = fraction of subpopulation j of the mature cow cohort culled

HRCULL = hours of labor per cow culled.

Reseeding and fertilizing pasture lands is one way that a manager can increase forage production. The costs of this activity are in the use of labor to perform the activity and in the physical supplies used.

$$RESORC_1(t) = (HRSEED + HRFERT)* \sum_{n=1}^{NLANDS} LAND_n \tag{5.6.18}$$

$$RESORC_5(t) = SPSEED* \sum_{n=1}^{NLANDS} LAND_n \tag{5.6.19}$$

$$RESORC_4(t) = SPFERT* \sum_{n=1}^{NLANDS} LAND_n \tag{5.6.20}$$

where:

$RESORC_1(t)$ = hours of labor used in reseeding and fertilizing of herd grazing lands--hours/DT

$RESORC_5(t)$ = quantity of seed used in reseeding grazing lands--kg/DT

$RESORC_4(t)$ = quantity of fertilizer used in fertilizing grazing lands of the herd--kg/DT

$LAND_n$ = area of land parcel n--hectares

NLANDS = number of distinct land parcels

HRSEED = hours of labor to seed per hectare

HRFERT = hours of labor to fertilize per hectare

SPSEED = units of seed applied per hectare

SPFERT = units of fertilizer applied per hectare.

Another event highly land oriented is harvesting of forage growth through mechanical means. This would be either for storage or for cash sale. Harvesting requires labor and utility usage, since fuel is an element of the composite resource "utilities."

$$RESORC_1(t) = HRHARV*DAYS* \sum_{n=1}^{NLANDS} MHR_n(t) \qquad (5.6.21)$$

$$RESORC_3(t) = SPHARV*DAYS* \sum_{n=1}^{NLANDS} MHR_n(t) \qquad (5.6.22)$$

where:

$MHR_n(t)$ = mechanical harvest rate from land parcel n--kg/day

DAYS = the number of days in a DT time increment

HRHARV = hours of labor per kg forage harvested--hour/kg

SPHARV = units of utilities per kg forage harvested--units/kg

$RESORC_1(t)$ = hours of labor required for forage harvesting in this time increment--hour/DT

$RESORC_3(t)$ = units of utilities used in forage harvesting in this time increment--units/DT.

$RESORC_6(t)$ is the quantity of land which is leased, either for grazing or crop production. HLEASE is this quantity; it is assumed to be constant over a single year.

Two activities are assumed to take place on an ongoing basis throughout the year. Repair of buildings, equipment, and land improvement, ie. fencing, is one. A second is the use of utilities to warm buildings and provide power for lights, ventilation, etc. The amount of utilities required is certainly a function of the time of year and of the activities that are seasonal because of climatic variations.

$$RESORC_3(t) = UNIT*\left(SPUTL1* \sum_{i=1}^{9} POP_i(t) + SPUTL2* \sum_{n=1}^{NSTOCK} FSTOCK_n(t) \right) \qquad (5.6.23a)$$

if t < TSPRNG, or t > TFALL

$$RESORC_3(t) = UNIT*\left[SPUTL3*\sum_{i=1}^{9} POP_i(t) + SPUTL4*\sum_{n=1}^{NSTOCK} FSTOCK_n(t)\right] \quad (5.6.23b)$$

if TSPRNG $\leq$ t $\leq$ TFALL

where:

$RESORC_3(t)$ = quantity of utilities used in this time increment to provide heat, power, lights, etc.--units/DT

$POP_i(t)$ = current cohort i population

$FSTOCK_n(t)$ = current feed stock n quantity--kgs

TSPRNG, TFALL = the onset and stoppage of plant growth, respectively

SPUTL1 = units of utilities per animal per month--units/animal/month

SPUTL2 = units of utilities per kg of feed stock per month--units/animal/month

SPUTL3 = units of utilities per animal per month--units/animal/month

SPUTL4 = units of utilities per kg of feed stock per month--units/animal/month

UNIT = DT/.083333.

Equations 5.6.23a, b represent the quantity of utilities needed to provide power for a DT time increment to buildings during wintering and grazing periods, respectively. SPUTL1, SPUTL2, SPUTL3, and SPUTL4 are monthly time-based parameters; the variable UNIT is a scaling factor to adjust the use of utilities to the time interval DT that has been used.

Repairs are also an ongoing activity that must be adjusted to get a quantity of resources used per DT time increment. Labor and repair materials are the only resources that are used in the equation modeling these repairs.

$$RESORC_1(t) = UNIT* \left(HREQIP* \sum_{i=1}^{9} POP_i(t) + HRFCAP* \sum_{n=1}^{NSTOCK} FSTOCK_n(t) + HRMAIN* \sum_{n=1}^{NLANDS} LAND_n \right) \quad (5.6.24)$$

$$RESORC_8(t) = UNIT* \left(SPREP1* \sum_{i=1}^{9} POP_i(t) + SPREP2* \sum_{n=1}^{NSTOCK} FSTOCK_n(t) + SPREP3* \sum_{n=1}^{NLANDS} LANDS_n \right) \quad (5.6.25)$$

where:

$RESORC_1(t)$ = quantity of labor used for repairs this time increment--hours/DT

$RESORC_8(t)$ = quantity of repair material used in this time increment--units/DT

$LAND_n$ = area of land parcel n--hectares

HREQIP = hours of labor per animal per month--hour/animal/month

HRFCAP = hours of labor per kg of feed stock per month--hour/animal/month

HRMAIN = hours of labor per hectare per month--hour/hectare/month

SPREP1 = units of repair material per animal per month/units/animal/month

SPREP2 = units of repair material per feed stock per month--units/kg/month

SPREP3 = units of repair material per hectare per month--units/hec/month

$POP_i(t)$ = current population of herd cohort i

These two equations model repair resource consumption as functions of the number of cattle, the quantity of feed stocks on hand, and the amount of land area in use.

Determination of animal production costs is completed by costing out the quantity of resources used in each DT time increment of the simulation. $RESORC_\ell(t)$, $\ell = 1, \ldots, 8$ gives the quantity of each of the resources used. $BPRICE_\ell(t)$, $\ell = 1, \ldots, 8$ gives the price per unit of resource as the resource variables RESORC(t) were defined in Table 5.2. Multiplication of the quantity of physical resource used by its current price is the cost of supplying that resource quantity in the current time increment. The production cost variables $ACOST_\ell(t)$ give the costs of animal production in the current time increment by appropriately grouping the production resources. This gives the production costs as defined in Table 5.1 as

$$ACOST_1(t) = RESORC_1(t)*BPRICE_1(t) \tag{5.6.26}$$

$$ACOST_2(t) = RESORC_8(t)*BPRICE_8(t) \tag{5.6.27}$$

$$ACOST_3(t) = RESORC_3(t)*BPRICE_3(t) \tag{5.6.28}$$

$$ACOST_4(t) = RESORC_2(t)*BPRICE_2(t) + RESORC_7(t)*BPRICE_7(t) \tag{5.6.29}$$

$$ACOST_5(t) = RESORC_4(t)*BPRICE_4(t) + RESORC_5(t) \tag{5.6.30}$$

$$ACOST_6(t) = RESORC_6(t)*BPRICE_6(t)*DT \tag{5.6.31}$$

$$ACOST_7(t) = \sum_{n=1}^{NSTOCK} STKFED_n(t)*CPRICE_n(t) \tag{5.6.32}$$

$$ACOST_8(t) = DT*\sum_{i=1}^{9} ADD_i(t)*APRICE_{PGRADE_i(t)}(t)*PAWATE_i(t) \tag{5.6.33}$$

$$ACOST_9(t) = OVHEAD*DT \tag{5.6.34}$$

where:

$ACOST_k(t)$ = production cost in category k in the current time increment--\$/DT

$PAWATE_i(t)$ = average weight of animals purchased and added to cohort i in this period--kg

$BPRICE_{\ell}(t)$ = the current price per unit of RESORC (t)--\$/unit

$RESORC_{\ell}(t)$ = the quantity of resource used in the current time increment of the simulation as determined from all events and activities which have occurred in the DT increment--units/DT.

DT = the simulation time increment in fraction of a year

NSTOCK = the number of feed stocks in use by the enterprise

$STKFED_n(t)$ = quantity of feed stock n fed to cattle in the current time interval--kg./DT

$CPRICE_n(t)$ = current price of feed stock n--\$/kg.

$APRICE_k(t)$ = current price of grade k cattle--\$/kg.

$PGRADE_i(t)$ = grade of cattle purchased as a addition for cohort i

OVHEAD = annual miscellaneous production costs--\$/yr

$ADD_i(t)$ = annual rate of herd additions

$= 0, \text{ if } ADDRT_i(t) \leq 0$

$= ADDRT_i(t), \text{ if } ADDRT_i(t) > 0.$

Total animal production costs for this time increment are

$$ACOST_{10}(t) = \sum_{\substack{i=1 \\ i \neq 7}}^{9} ACOST_i(t)$$

$ACOST_7(t)$ values are excluded from this total because they are counted in $CCOST_3(t)$ where the purchases of feed crops are itemized. Double counting of expenses would occur if $ACOST_7(t)$ were included as a part of the total running operating costs of the enterprise. $ACOST_7(t)$ is useful, however, because the current value of feed stocks fed to the herd is a valuable item of status information for management.

Table 5.3 itemizes the entire parameter list used in determining production costs and presents a sample value. Other values

Table 5.3 Parameter Values and Definitions for the Production Cost Element of the Financial Component

Parameter	Value	Definition
OVHEAD	5000.	annual overhead and miscellaneous costs--$
DEFLAT	0.91	ratio of crop production costs to prices
SPBRED	0.5	units of breeding supplies per cow servicing
SPVACC	1.0	units of vaccination supplies per calf
HRCALV	0.05	hours of labor per calf born
HRFED1	.00047	hours of labor per kg. feed fed
HRBRED	.25	hours of labor per cow servicing
HRVACC	0.03	hours of labor per calf vaccinated
HRWEAN	1.75	hours of labor per calf weaned
HRCULL	0.2	hours of labor per cow culled
NRCAST	0.2	hours of labor per male calf castrated
HRSEED	0.04	hours of labor per hectare of land seeded
HRFERT	0.04	hours of labor per hectare of land fertilizer
HRHARV	.0021	hours of labor per kg. forage harvested
HREQIP	0.03	hours of labor for equipment repair per animal per month
HRFCAP	.00002	hours of labor for repair per kg. feed stocks per month
HRMAIN	.00475	hours of labor for repair per hectare of land per month
SPUTL1	2.5	units of utilities per animal per month during wintering
SPUTL2	.0001	units of utilities per kg. feed stock per month during winter
SPUTL3	0.	units of utilities per animal per month during grazing
SPUTL4	.00001	units of utilities per kg. feed stock per month during grazing
SPUTL5	0.02	units of utilities per kg. forage harvested
SPSEED	10.0	units of seeds used per hectare sown
SPFERT	50.0	units of fertilizer per hectare fertilized
SPREP1	0.10	units of repair material per animal per month
SPREP2	.000013	units of repair material per kg. feed stock per month
SPREP3	0.01	units of repair material per hectare of land per month
HLEASE	0.	hectares of leased land per year

can, of course, be used by reading in any desired value during program initialization and start up. Detailed cost examination of individual enterprise records and operation should serve to obtain better values than these given. A final note--OVHEAD represents miscellaneous costs and the salary that a manager would obtain that is separate from hours of physical labor that he might perform.

Debt of the enterprise has been divided into the arbitrary classifications of short-term and long-term. This has been done to draw the needed distinction between borrowing for land purchases, e.g., mortgages, and borrowing for operating capital. Long-term debt is assumed to only decrease or remain constant during individual runs of the model. Short-term debt can be increased by borrowing at special decision points, the interest rate and repayment schedule can also be renegotiated, whereas these are fixed for long-term debt. Long-term debt is therefore handled by the following equations.

$$CAPTL_1(t) = CAPTL_1(t-dt) - PMONTH(t) \qquad (5.6.36)$$

$$PINTER(t) = CAPTL_1(t)*CAPTL_3*DT \qquad (5.6.37)$$

where:

$CAPTL_1(t)$ = current long-term debt--\$

$CAPTL_2$ = contracted monthly repayment of long-term debt--\$/month

$CAPTL_3$ = annual interest rate for long-term debt

$PINTER(t)$ = payment of interest on long-term debt in this time increment--\$/DT

$PMONTH(t)$ = repayment of principal on long-term debt in time increment--\$/DT

0, if $CAPTL_1(t) = 0$

$CAPTL_1(t)$, if $CAPTL_1(t) \leq CAPTL_2(t)$

$CAPTL_2(t)$, if $CAPTL_1(t) > CAPTL_2(t)$.

Short-term debt is handled analogously except that additional loans can be obtained, and the interest rate and repayment variables are functions of time.

SDEBT(t) = SDEBT(t-dt) - SMONTH(t) + SLOAN(t) (5.6.38)

SINTER(t) = SDEBT(t)*SDEBTR(t)*DT (5.6.39)

where:

SDEBT(t) = current short-term debt--$

SDEBTR(t) = current annual interest rate on short-term debt

SLOAN(t) = short-term debt incurred this time period--$/DT

SINTER(t) = payment of interest on short-term debt--$/DT

SREPAY(t) = monthly repayment of short-term debt--$/month

SMONTH(t) = repayment of principal on short-term debt--$/DT

0, if SDEBT(t) = 0

SDEBT(t), if SDEBT(t) $\leq$ SREPAY(t)

SREPAY(t), if SDEBT(t) > SREPAY(t).

The total payments of principal and interest, both long- and short-term, are aggregated into $CAPTL_5(t)$.

$CAPTL_5(t)$ = PMONTH(t) + PINTER(t) + SMONTH(t) + SINTER(t) (5.6.40)

Inclusion of debt in its various forms and the required repayment of debt in an important aspect of this model, because of its significant contribution to negative cash flows. Debt repayment on common terms is a constant cash outflow, whereas cash inflow is highly concentrated and seasonal. This leads to the common occurence of negative cash flows during the bulk of a year interrupted by singular periods of heavy cash inflow. Short-term debt is a key feature allowing operating capital to remain positive, thus permitting continued enterprise operation.

The final financial element included in this model of enterprise finances is taxation. Taxes take two forms--income taxes on the gross profits of the enterprise, and property taxes on its real property. Since taxation is a highly localized process, the model developed here is rather basic and should be made more specific for actual operation in a fixed environment. Income taxes are assumed due in one payment on April 1 for gross income earned in the preceding calendar year. Property taxes are paid twice yearly, on January 1, and on July 1. Depreciation is taken on depreciable assets (assumed to have a common tax life) at the time of tax payment and is computed using sum of the digits. Thus taxable income is accumulated from January 1 using

$$TAXINC(t) = TAXINC(t-dt) + TPGRP(t) - CAPTL_4(t) \qquad (5.6.41)$$

where:

$TAXINC(t)$ = accumulated yearly taxable income--$

$CAPTL_4(t)$ = annual depreciation--$

$TPGRP(t)$ gross profit in this time period--$/DT.

Equation 5.6.41 is used to determine the current contribution to taxable income from the gross profits of the current simulation time increment. Taxable income is an accumulated variable which begins with an initial value of zero on January 1 of each year; in simulation runs which last longer than a single year, the variable TAXINC(t) is reset to zero when the simulated time equals January 1. At this time two actions occur: TAXLIB(t) is set equal to the current value of TAXINC(t), and TAXINC(t) is set equal to zero. TAXLIB(t) represents the taxable income from the previous year which is subject to

represents the average depreciation lifetime of these assets. The sum-of-the digits method of depreciation is used to determine the actual depreciation charge that can be made in each tax year. This computation is made by the model on April 1 of each simulated year and is subtracted from taxable income at that point. $CAPTL_4(t)$ is the variable name used to represent this depreciation variable; it is determined by equation 5.6.42 to be

$$CAPTL_4(t) = \left(\frac{LIFE - INT(t-t_0)}{\sum_{t=t_0}^{LIFE} INT(t-t_0)} \right) *LVALUE \tag{5.6.42}$$

where:

$CAPTL_4(t)$ = current amount depreciated in this time increment--$

LIFE = the depreciable lifetime allowed by tax law--years

INT(s) = a function which integerizes the value s

LVALUE = the original purchase price being depreciated//$.

$CAPTL_4(t)$ is equal to zero at all times other than April 1 of each year.

Property taxes are paid on the actual real estate actually owned. The variables $LAND_n$, giving the area of the n^{th} land parcel, are not necessarily owned; some could be leased. The true area subject to tax is the difference between total land and leased land.

$$TAX(t) = 0.50*PROTAX* \left(\sum_{n=1}^{HLANDS} LAND_n - HLEASE \right) \tag{5.6.43}$$

if t = January 1, or July 1

income tax in the current year. As long as income taxes have not yet been paid, the variable TAXLIB(t) remains at the value that it was set to on January 1. On April 1 tax is paid at the current rate payable by corporate farms; TAX(t) is the income tax paid. Then

$$\text{TAX}(t) = \begin{cases} 0.0, \text{ if } t \notin \text{ April 1, January 1, July 1} \\ \text{TRATE*TAXLIB}(t), \text{ if } t = \text{April 1} \end{cases}$$

where:

TAX(t) = the dollars in taxes paid this time increment of the simulation--$/DT

TRATE = 0.5, the tax rate on gross taxable income

TAXLIB(t) = the gross taxable income from the previous tax year--$.

A significant factor involved in determination of taxable income is depreciation-any allowable depreciation is subtracted off of gross profits when computing taxable income. Depreciation is itself a complex subject which is highly controlled by rules and regulations of various tax authorities. Additionally, it is completely specific to the individual enterprise being studied since the heart of depreciation is the quantities of depreciable assets owned by the enterprise and the allowable depreciable lifetime. This financial model makes a very modest effort to include depreciation primarily because of its potential significance in causing differences in the dynamic computation of cash flow and net profit.

The model of depreciation adopted here employs the general idea of an average purchase value of assets owned and a corresponding average depreciable lifetime. LVALUE represents the total purchase prices of all depreciable assets owned by the enterprise, while LIFE

where:

PROTAX = annual tax on land--\$/hectare-year

$LAND_n$ = area of land parcel n -- hectares

HLEASE = area of land leased -- hectares.

The combination of taxes on property and on income is handled by the variable TAX(t). TAX(t) is zero at all times of the year except for the dates January 1, April 1, and July 1.

Subroutine FINANC provides the overall organization of the financial component by calling the above simulation models of the various financial elements. Gross profits in the current time increment is the difference between revenues and payments.

$$TPGRP(t) = AREV_{10}(t) + CREV_{NCROPS+1}(t) - ACOST_{10}(t) - CCOST_4(t) - CAPTL_5(t) \quad (5.6.44)$$

where:

TPGRP(t) = current period's gross profit--\$/DT

$AREV_{10}(t)$ = total animal revenue earned in this period--\$/DT

$CREV_{NCROPS+1}(t)$ = total crop revenue earned in this period--\$/DT

$ACOST_{10}(t)$ = total animal production costs in this period--\$/DT

$CCOST_4(t)$ = total crop production costs in this period--\$/DT

$CAPTL_5(t)$ = total debt payments in this period--\$/DT.

Cash flow in this period is the difference between gross profits and tax payments, if any.

$$CASH(t) = TPGRP(t) - TAX(t) \quad (5.6.45)$$

where:

CASH(t) = current time increment cash flow--\$/DT

TAX(t) = taxes paid in this time increment, either income or property--S/DT

TPGRP(t) = gross profits of the enterprise in this time increment--\$/DT.

Cash flow is an important management decision-making variable because it reflects the actual transfer of cash into and out of the enterprise. As explained earlier, beef cattle enterprises are characterized by steady net cash outlfows during most of the year, interrupted by heavy cash inflows when products are sold. These seasonal sales products are, of course, weaned calves and excess forage and crop production. Finally, net profit in the period is the difference between cash flow and depreciation, giving

$$TPNP(t) = CASH(t) - CAPTL_4(t) \qquad (5.6.46)$$

where:

TPNP(t) = net profit in this time increment--\$/DT

$CAPTL_4$ = depreciation taken in this time increment--\$/DT.

Operating capital of the enterprise is, of course, affected by cash flow and borrowing, giving

$$WCAPT(t) = WCAPT(t-dt) + SLOAN(t) + CASH(t) \qquad (5.6.47)$$

where:

WCAPT(t) = current level of operating capital--\$

SLOAN(t) = short-term loans incurred in this time increment--\$.

Yearly accumulated profits, both gross and net, and cash flows are important variables in analyzing the overall operation of this enterprise. The subroutine FINANC determines such annual variables by summing the individual incremental values for each calendar year.

This gives

$$TAGRP_m(t) = TAGRP_m(t-dt) + TPGRP(t) \quad (5.6.48a)$$

$$TANP_m(t) = TANP_m(t-dt) + TPNP(t) \quad (5.6.48b)$$

$$TACASH_m(t) = TACASH_m(t-dt) + CASH(t) \quad (5.6.48c)$$

where:

$TAGRP_m(t)$ = accumulated gross profits to date in the m^{th} year of operation--$

$TANP_m(t)$ = accumulated net profits to date in the m^{th} year of operation--$

$TACASH_m(t)$ = accumulated cash flow to date in the m^{th} year of operation--$

m = index of the year of operation since the beginning of the simulation

= 1, if $0 \leq t < 1$

= 2, if $1 \leq t < 2$

= DUR, if $DUR-1 \leq t < DUR$

DUR = time specified as the final time horizon of model time simulation.

Computation of present discounted values of these three annual variables is extremely helpful in evaluating the impact of specific management policies over time. Undiscounted values can be quite misleading since the time value of money and the impact of inflation are not accounted for. When the simulation has reached the final time horizon (t = DUR) the following values are computed for a variety of discount rates.

$$PRV_{1i} = \sum_{m=1}^{M} \frac{TAGRP_m(t)}{(1 + DFLATR_i)^m} \quad (5.6.49a)$$

$$PRV_{2i} = \sum_{m=1}^{M} \frac{TANP_m(t)}{(1 + DFLATR_i)^m} \tag{5.6.49b}$$

$$PRV_{3i} = \sum_{m=1}^{M} \frac{TACASH_m(t)}{(1 + DFLATR_i)^m} \tag{5.6.49c}$$

where:

PRV_{1i} = present discounted value of annual gross profits using discount rate i

PRV_{2i} = present discounted value of annual net profits using discount rate i

PRV_{3i} = present discounted value of annual cash flows using discount rate i

$DFLATR_i$ = discount rate i

M = the integer number of years of the simulation run.

The financial component is an important part of the simulation model of the enterprise; it is central to evaluation of alternative management strategies because it reduces physical events and activities to dollars and cents. Most applications using the model will be interested in the financial aspects of management strategies rather than the specifics of the physical events that have occurred as a result of the strategy. The financial model developed in this section is certainly adequate for the purposes of this thesis, but in use by specific enterprises there will need to be certain changes to tune the financial model to the specific enterprise operating environment. Tax rates and the parameters listed in Table 5.3 are the main means of tuning the model; these are entered during the initialization of the computer program. The details of this initialization can be found in the User's Guide to the Beef Cattle Enterprise Simulation Model, Chapter Three.

V.7 Simulation Model Calling Structure

The previous sections of this chapter have defined the mathematical models that describe the various processes of the system. The simulation models that implement these equations are written in FORTRAN, and can be found in the User's Guide ..., Chapter Four. Figure 4.13 and others have referred the reader to the general calling structure of the simulation model. This section will indicate the exact subroutine calling structure used, noting calls to subroutines from within other subroutines by indentations to the right.

```
MAIN . . . . . . . . . . .  . the main program
      GENERT
      EXOG
      HDMOG4 . . . . . . . .  . population demography
              BIRTH2* . . . . . . birth rates
                      BIRAT*
              DVDPLR
              DLVDPL
              DDPLR
      WEIGHT . . . . . . . .  . cattle weights
      FEEDS  . . . . . . . .  . feed stock accounting
      FORAGE . . . . . . . .  . forage growth
      INQUIR . . . . . . . .  . recognition of decision
                                points
      RESPNS# . . . . . . . . . reading control inputs
      NORMAL . . . . . . . .  . endogenous decision making
```

* developed by Margaret Schuette[48]

\# called only when a decision point is encountered by INQUIR

MAIN, continued

.
.
.

CONSUM . . . . nutrient impacts

NUTRN . . . . shell for Schuette subroutines

COWCYC*

ALAC*

GROFEM*

GROMAL*

FINANC . . . . financial accounting

REVENU

PRCOST

CAPTAL

TAXSUB

PRINTR . . . . intermediate simulation increment printing.

This listing of subroutine calls is only a brief reference to the organization of the computer program and its subroutines which actually simulate the system behavior. The full and complete details of the FORTRAN programming can be found in Chapter 4, User's Guide to the Beef Cattle Enterprise Simulation Model.

V.8 Summary

This chapter has developed the mathematical models upon which the simulation model is based. These models meet the requirements of the problem statement, but considerable room for improvement and extension remain. The four physical system components--cattle demography, forage growth, feed stock accounting, and nutrient impacts--provide the model user with the necessary detail to be useful in investigating management decision making strategies. The management decision making component itself has been shown to involve both endogenous decisions made by the model and exogenous decisions made by the model user. Several secondary components have been explained in terms of handling necessary details such as correct selection of exogenous input variables and financial accounting. The following chapter will outline various means used to validate the model, that is, to verify that it properly describes the beef cattle enterprise.

V.9 Glossary of Variables

The following alphabetical listing of variables includes all variable names used in the preceding sections of this chapter. These same names are used whenever feasible in the computer program and subroutines, as listed in Appendix 1. Parameter names are not included here, but may be found in the text as they are used.

1. $ACOST_m(t)$ = the production cost in the current DT time increment for the m^{th} cost subdivision--\$/DT

2. $ACTED_{kn}(t)$ = quantity of feed stock n required for feeding in the current DT(k=2), or the winter season (k=1)--kg

3. $ACTIVE_n(t)$ = forage density photosynthetically active in the n^{th} land parcel--kg/hectare

4. $ADDRT_i(t)$ = the annual rate of addition of animals to herd cohort i--#/yr

5. AGEMIN = the minimum age of calves weaned--years

6. $AHR_n(t)$ = the rate of forage harvest by grazing in land parcel n--kg/day

7. $ALGD_i(t)$ = the average price grade of cattle in cohort i currently

8. $ALLOC_i(t)$ = total quantity of feed allocated to individuals in cohort i per day--kg/day

9. $ALWT_i(t)$ = the current average weight of cattle in cohort i--kg

10. $APFUTR_{mk}(t)$ = current expectation of the value of the k^{th} grade cattle price m DT's into the future--\$/kg

11. $APRICE_k(t)$ = the current market price of cattle of grade k--\$/kg

12. $AREV_i(t)$ = revenue earned in the current time increment from sales of cattle from cohort i--\$/DT

13. $ASALES_i(t)$ = the number of cattle sold in the current time increment from cohort i--#/DT

14. $ASELL_i(t)$ = the proportion of the current population of cohort i that is to be sold in this time increment

15. $AVGGRD_i(t)$ = the average price grade of cattle sold in this time increment from cohort i

16. AVGTMP(t) = the average temperature in the current DT time increment--°C

17. $AVGW_i(t)$ = the average weight of cattle sold in this time increment from cohort i--kg

18. $AWF_n(t)$ = the animal harvest wastage factor in the current time increment for land parcel n

19. $BASEDG_n(t)$ = the basic digestibility factor in the current time increment for land parcel n

20. BEGCAV = the time in the year at which cows begin to calve

21. $BFRAC_{il}$ = the l^{th} point in the curve describing the accumulated calving pattern for cohort i

22. $BPFUTR_{ml}(t)$ = the current expectation of the value of the l^{th} production resource price m DT's into the future--$/unit

23. $BPRICE_l(t)$ = the current market price for the l^{th} resource of production--$/unit

24. $BR_i(t)$ = the current birth rate on an annual basis for the i^{th} herd cohort--#/yr

25. $CAPTL_m(t)$ = the current value of the m^{th} financial variable

26. $CASH_l(t)$ = current cash flow in this time increment--$/DT

27. $CATTIN_{ikl}(t)$ = the quantity of TDN allocated to members of herd cohort i per day from concentrates (k=1), or roughages (k=2), under feed plan l

28. $CCOST_l(t)$ = the crop production cost in the current time increment for the l^{th} crop cost subdivision--$/DT

29. CFINAL = the proportion of the existing forage in each land parcel that is to be harvested at the end of the growth season (TFALL)

30. $CNCAL_i(t)$ = the quantity of concentrates allocated to cohort i for the current time increment--kg/DT

31. $CNCFRC_{in}(t)$ = the fraction of the concentrate TDN allocation to cohort i to be obtained from feed stock n

32. $CPAT_{ijk}$ = the fraction of the j^{th} subpopulation of cohort i to have calved by $CTIM_{ijk}$

33. $CPFUTR_{mn}(t)$ = the current expectation of the value of the n^{th} feed stock price 2m DT's into the future--$/kg

34. $CPRICE_{n}(t)$ = the current market price of feed stock n--$/kg

35. $CREV_{n}(t)$ = the revenue earned from sales of feed stock n in the current time increment--$/DT

36. $CROP_{nl}(t)$ = crop production in the current time increment for feed stock n--kg/DT

37. $CROPG_{n}(t)$ = annual crop production to date of feed stock n--kg

38. $CRQUAL_{nl}(t)$ = the TDN value of the current quantity of feed stock n being harvested this time increment

39. $CSALES_{n}(t)$ = the quantity of feed stock n sold in the current time increment--kg/DT

40. $CTIM_{ijk}(t)$ = the time of year that calves will be born of female animals from subpopulation j of the ith cohort as a result of the kth servicing--years

41. $CULFRC_{j}(t)$ = the fraction of the j^{th} subpopulation of the mature cow cohort that is to be culled at TCULL

42. C2 = fraction of the output of the male calf cohort transferred to the young bull cohort after weaning

43. C3 = fraction of the output of the female calf cohort transferred to the slaughter heifer cohort

44. C4 = fraction of the output of the male calf cohort sold on the market as weaned calves

45. C5 = fraction of the output of the female calf cohort transferred to the replacement heifer cohort

46. C6 = fraction of the output of the male calf cohort sold on the market after weaning

47. C9 = fraction of the output of the female calf cohort sold on the market as weaned calves

48. C10 = fraction of the output of the replacement heifer cohort transferred to the mature cow cohort

49. C11 = fraction of the output of the bred heifer cohort sold on the market

50. DAYS = the number of days in the DT time increment

51. $DELAY_i(t)$ = the current length of time required for the average member of cohort i to pass through the maturity interval modeled by that cohort--yr

52. $DFLATR_i(t)$ = the i^{th} discount rate used to compute the discounted present values of financial variables at the end of the simulation run

53. $DGAIN_{ij}(t)$ = the rate of weight gain for the j^{th} subpopulation of cohort i--kg/day

54. $DIGEST_n(t)$ = the TDN value of the forage in land parcel n at the current time

55. $DISTFD_{inl}(t)$ = the fraction of the cohort i allocation of concentrates (if n is a feed concentrate), or of roughages (if n is a feed roughage) to come from feed stock n under feed plan l

56. $DMI_{ij}(t)$ = the dry matter intake per day of a member of subpopulation j of cohort i--kg/day

57. $DMITDN_{ij}(t)$ = the average TDN value of the dry matter intake of members of the j^{th} subpopulation of cohort i

58. DR_i = the annual death rate for herd cohort i members--fraction/year

59. DT = the time increment used in the simulation--year

60. DUR = the time horizon over which the simulation is to be run--years

61. $DURB_i(t)$ = the duration of the breeding season for members of cohort i--years

62. $EFORG_{ij}(t)$ = quantity of energy available for weight gain after maintenance needs satisfied--mcal

63. $EGAIN_i(t)$ = energy value of the feed intake in terms of growth for cohort i--$\frac{\text{mcal gain energy}}{\text{kg feed}}$

64. $EMAIN_i(t)$ = energy value of the feed intake in terms of maintenance for cohort i--$\frac{\text{mcal maint. energy}}{\text{kg feed}}$

65. ENDCAV = the time at which the calving season is complete--year

66. EVAP = the equivalent height of water evaporated per day--cm/day

67. $F_n(t)$ = the rate of transfer of growth from roots to greenery in land parcel n--kg/hectare/day

68. FATFAC = parameter relating predicted daily gains for cattle at their cohort weight maximum into price grade increases

69. $FCOST_i(t)$ = the cost of retaining the population of cohort i for an additional time increment at the planned feeding schedule--$

70. $FDENSE_n(t)$ = forage digestibility factor based on forage density per animal in land parcel n

71. $FEDTDN_i(t)$ = the average TDN value of the roughage fed to cohort i from feed stock sources

72. $FEEDAL_i(t)$ = the quantity of roughage allocated to cohort i for the current increment of time--kg/DT

73. $FLEVEL_n(t)$ = the minimum quantity of forage needed to sustain animals grazing in land parcel n per DT time increment--kg

74. $FORGAL_i(t)$ = the quantity of roughage allocated to cohort i as a result of grazing policy--kg/DT

75. $FORTDN_i(t)$ = the TDN value of the forage from roughage allocation to cohort i

76. $FPLANS_l(t)$ = the time at which the l^{th} feed plan for the herd is completed--year

77. $FQUAL_n(t)$ = the current TDN value of the n^{th} feed stock

78. $FQUAN_n(t)$ = the quantity of feed stock n in the current time increment which is carried over from the previous period's stocks--kg

79. $FRCLOS_n(t)$ = the annual loss rate of feed stock n--fraction/year

80. $FREV_i(t)$ = expected marginal revenue gained from retention of cohort i animals an additional DT time increment--$

81. FRQUAL(t) = forage digestibility factor relating current forage digestibility to time in the growth season

82. $FSTOCK_n(t)$ = the current level of feed stock n supplies--kg

83. $FTOL_l$ = the absolute fractional deviation between current feed stock levels and seasonal requirements allowed

84. $GRADE_{ij}(t)$ = the current price grade of cattle in the j^{th} subpopulation of cohort i

85. $GRN_n(t)$ = the current quantity of forage existing within land parcel n--kg

86.	$GRNDEN_n(t)$ =	the quantity of forage greenery available per animal per day in land parcel n--kg/animal/day
87.	IFLAG =	an indicator flag describing the existence of regular and special decision points
88.	INB_{ij} =	the number of servicings during the breeding season for animals in the j^{th} subpopulation of cohort i
89.	INTCAV =	the number of intervals of length one-half month within the calving interval
90.	$KK_i(t)$ =	the number of subpopulations within cohort i
91.	$LAND_n$ =	the area of land parcel n--hectares
92.	LIFE =	the average depreciable life of the mix of depreciable assets owned--years
93.	LVALUE =	the purchase price in total of the depreciable assets owned--$
94.	$MHR_n(t)$ =	the rate of mechanical harvest of forage growth in land parcel n--kg/day
95.	MWF =	the wastage factor in mechanical harvest of forage
96.	NCROPS =	the number of feed stocks potentially used by the enterprise
97.	NLANDS =	the number of land parcels
98.	NSTOCK =	the number of feed stocks potentially used by the enterprise
99.	$PDSTRB_{ni}(t)$ =	the fraction of the population of cohort i grazing in land parcel n
100.	PERC(t) =	the equivalent height of water percolating down below effective root depth--cm/day
101.	$PGRADE_i(t)$ =	the average grade of animals purchased and added to cohort i
102.	$PHOTO_n(t)$ =	the net growth rate of forage in land parcel from photosynthetic energy conversion--kg/day
103.	$PINDEX_n(t)$ =	relative age of forage existing in land parcel n--days

104. PINTER(t) = payments of interest in the current time increment on long-term debt--\$/DT

105. PMONTH(t) = payments on principal in this time increment for long-term debt--\$/DT

106. $POP_i(t)$ = the current population of cohort i

107. PROTAX = the current property tax rate on an annual basis--\$/hectare/year

108. $PRQUAL_n(t)$ = the TDN value of feed stock n purchases

109. PRV_{mk} = the discounted present value of the annual values of gross profit (m = 1), net profit (m=2), or cash flow (m=3), using discount rate k

110. RAIN(t) = the current rate of rainfall--cm/day

111. $REACTD_n(t)$ = the current intentions of feed stock n net purchases at the end of the growth season (TFALL)--kg

112. REMOVL(t) = the current fraction of the existing forage in each land parcel to be harvested at each harvest time

113. $RESORC_l(t)$ = the quantity of production resource l used in the current time increment--units

114. RGRAZE(t) = the minimum quantity of forage required to maintain the cattle herd grazing in the current time increment--kg/DT

115. $RHGAL_i(t)$ = the overall roughage allocation to herd cohort i in this time increment--kg/DT

116. $RHGFRC_{in}(t)$ = the fraction of the roughage TDN allocation (from feed stocks) to cohort i to be obtained from feed stock n

117. $RIN_{ij}(t)$ = the intermediate output rate in the delay model of cohort i corresponding to subpopulation j

118. $ROOT_n(t)$ = the current density of roots in land parcel n--kg/hectare

119. $ROUT_i(t)$ = the current output rate of animals from herd cohort i--#/year

120. $RPOP_i(t)$ = the population of cohort i which is reproductively characteristic of cohort i behavior

121. SDEBT(t) = the current level of short-term debt--$

122. SDEBTR(t) = the annual interest rate required for short-term debt

123. SINTER(t) = payments of interest made in the current time increment for short-term debt--$/DT

124. SLOAN(t) = current quantity of short-term debt acquired this time increment--$/DT

125. SM(t) = the current level of soil miosture within an effective root depth--cm

126. SMF(t) = the current value of the soil moisture quality index

127. SMONTH(t) = the current repayments of principal of short-term debt--$/DT

128. SNF(t) = the current value of the soil nutrients quality index

129. $SNUT_n(t)$ = the current level of soil nutrients in land parcel n--units

130. SOLAR(t) = the current average daytime rate of incoming solar radiation--langleys/day

131. SPLIT = the fraction of roughage consumption derived from feed stock roughages when an excess roughage allocation has been made

132. $SPOIL_n(t)$ = the annual rate of TDN decline in storage for feed stock n

133. SREPAY(t) = the current monthly payment to principal required for the outstanding short-term debt--$/month

134. $STKFED_n(t)$ = the quantity of feed stock n allocated to herd consumption in the current time increment--kg/DT

135. $STKPUR_n(t)$ = the current quantity of feed stock n purchased in this time increment--kg/DT

136. $STOCKL_n(t)$ = the stocking level of grazing cattle in land parcel n--#/hectare

137. $SUBPOP_{ij}(t)$ = the current number of animals in the j^{th} subpopulation of cohort i

138. $SUMTPF(t)$ = the current value of the integral of the temperature quality index (TPF)--units

139. $TACASH_m(t)$ = the annual cash flow in year m of the enterprise simulation--\$/year

140. $TAGRP_m(t)$ = the annual gross profit in year m of the enterprise simulation--\$/year

141. $TANP_m(t)$ = the annual net profit in year m of the enterprise simulation--\$/year

142. $TAX(t)$ = the number of dollars of taxes paid in this time increment to all authorities--\$/DT

143. $TAXINC(t)$ = taxable income in the current calendar year to date--\$

144. $TAXLIB(t)$ = income from the previous calendar year liable for income taxes currently--\$

145. $TBRD_i(t)$ = the current value of the date on which breeding of cohort i is to commence--year

146. $TCULL(t)$ = the current time at which culling of the mature cow cohort is to occur--year

147. $TDMIC_i(t)$ = the quantity of concentrates consumed by herd cohort i in the current time increment--kg/DT

148. $TDMIR_i(t)$ = the quantity of roughage consumed by herd cohort i in the current time increment--kg/DT

149. $TDNC_i(t)$ = the average TDN value of the concentrate allocation to herd cohort i

150. $TDNR_i(t)$ = the average TDN value of the roughage allocation to herd cohort i

151. TFALL = the time at which the growth season stops--year

152. $TFRAC_{mi}$ = the fraction of the weaned female calves in the m^{th} cohort subpopulation older than the youngest subpopulation weaned which is transferred to cohort i

153. $TGREEN(t)$ = the total quantity of greenery available for grazing by cattle at time t--kg

154. $TMHR_l(t)$ = the time at which the l^{th} mechanical harvest of forages is to occur--year

155. TPF(t) = the current value of the temperature quality index

156. TPGRP(t) = total dollars of gross profit earned in the current time period--$/DT

157. TRATE = the rate of taxation for businesses on taxable income

158. TSPRNG = the time at which the growth season is begun--year

159. TWEAN(t) = the time at which the calf cohorts are to be weaned--year

160. VGREEN(t) = the average TDN value of the total forage currently available for grazing

161. $W_{ij}(t)$ = the average weight of members of the j^{th} subpopulation of cohort i--kg

162. WCAPT(t) = the current level of working capital on hand--$

163. $WGTMAX_i$ = the maximum weight that members of cohort i can achieve--kg

164. $XCPROD_n(t)$ = the expected production of feed stock n during the growth season--kg

165. $XCQUAL_n(t)$ = the expected TDN value of the production of feed stock n expected

166. $XPECTA_k(t)$ = the expected price of cattle of grade k at time t--$/kg

167. $XPECTB_l(t)$ = the expected price of the l^{th} resource of production at time t--$/unit

168. $XPECTC_n(t)$ = the expected price for the n^{th} feed stock at time t--$/kg

169. $ZX3_n(t)$ = the fraction of the photosynthetically converted energy growth rate used for root growth

CHAPTER VI

MODEL TESTING AND VALIDATION

Validation is, in its essence, a process of verifying that a model correctly represents the real world process that it is supposed to represent. Model validation is an essential step in model development because use of an invalid model could easily be worse than no model at all. Validation of simulation models is more difficult to achieve than validation of other model forms, because of the great complexity that simulation models are commonly used to portray dynamically. This chapter will seek to review some approaches to model validation in general, present evidence to demonstrate the simulation model's validity, and summarize more sophisticated procedures for developing user confidence in this model.

VI.1 Approaches to Validation

In some respects the process of validating a model is a search for truth. What is desired is that the model truly represent the real system. Unfortunately, demonstration of truth has been subordinated to questions about truth and truthfulness themselves in the literature. Philosophers through the ages have failed to resolve these questions in any generally acceptable manner. In the realm of economic models there are three approaches to establishment of model truthfulness about the real world.[1] Robbins [44] espouses the thinking that models must be ultimately based on unverifiable basic assumptions that have to be accepted or rejected on their own merits. The model should correctly evolve from them, but the basic assumptions themselves are not testable. Hutchinson [27] totally rejects this approach and maintains that nothing is proved true until it can be empirically tested. This includes the basic model assumptions; they are suspect where assumptions cannot be supported by data. Freidman [17] represents the Positive Economics school of thinking, which would find truth if a model correctly predicts behavior. Some question this line of thinking by stating that it leads to use of models which may predict behavior correctly, but which are based on obviously false assumptions. Some also draw a distinction between positive and normative models,[2] but this beef cattle enterprise simulation model contains both positive and normative characteristics. We are led to the conclusion that this model must produce the proper behavior but must also be developed according to realistic and valid assumptions.

In a practical sense validation is a two-phase process for simulation models. First, there is the problem of validating, or

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[1]T. H. Naylor, J. L. Balintfy, D. S. Burdick, and K. Chu, Computer Simulation Techniques (New York: Wiley, c. 1966), Chapter 8.

[2]Definitions from Gilmour [18], Chapter 1:
Positive--a model which must show reasonable correspondence to the real system
Normative--a model which indicates a desirable level of operation for the real system which may or may not be currently achieved.

verifying, that the simulation model correctly represents the mathematical model. Here the major difficulty is debugging computer programs and checking that approximations made to achieve a solution are giving acceptably low errors. Second, there is the more difficult problem of verifying that the mathematical model really does represent the real world system. The less well understood the real world system is the greater the difficulty in validating the model.

A common occurrence in development of simulation models is discovery of areas that have been ignored by conventional researchers, even though strong understanding is needed to develop a model of an entire system. This uneven level of understanding of parts of a system leads to difficulties in validation, because it is the entire system behavior that is of interest. The "weak links" which exist, because the necessary exploratory research has not been done, inhibit generation of confidence in a system model. A beneficial result of development of simulation models is the discovery of these poorly understood areas, if then resources for research can be reallocated to these problem areas.

Several specific proposals for validating simulation models have been developed. These borrow from one another rather heavily, and perhaps this is due to the type of problem that the developer was familiar with at the time he proposed his procedure. Gilmour [18] proposes the following steps:

1. determination of face validity

2. determination of output validity through

   a. analysis of stability
   b. historical comparison
   c. comparative analysis of output after making assumption changes.

Popper [41] suggests that the goal of such exercises is increasing confirmation in the truthfulness of the model. Therefore the proper procedure is to make tests of the model; the more tests the model passes, the greater the degree of confirmation in its truthfulness.

A procedure which seems generally applicable to many situations proposes a hierarchy of testing stages. The procedure is to work from easy to difficult as confidence in the model's validity is developed. These validation steps, in order of increasing difficulty, are:

1. logical consistency

2. tracking historical data

3. satisfaction of expert eyeballing

4. prediction of the future.

One accomplishes these steps through study of model output over time by varying parameters to observe the direction of output changes, by determining that the parameter sensitivities reflect real system sensitivities, and in general by immersing oneself in the model for lengthy periods to understand how the simulation behaves. Satisfaction of experts in appropriate areas is an excellent indication of validation. This satisfaction can be achieved, in all likelihood, only after an iterative series of presentation reviews, criticism,

and model changes. Prediction is the final test of model validity, to be confirmed or rejected by real events.

Complete certainty in model validity is never possible; this means that models are used with less than perfect confidence in their predictions. Model use and continuing refinement should be linked together to insure that the model increases in validity as time passes. Chapter 8 of this dissertation will suggest several areas wherein greater sophistication in the component models would prove beneficial to both generation of confidence and usefulness to model users.

VI.2 Validation Tests

This section will define and present examples of validation tests for the four steps reviewed in section one: logical consistency, tracking historical data, satisfaction of expert eyeballing, and prediction of the future. It should be understood that validation testing has not been limited to examples presented here.

Logical Consistency

Logical consistency is the requirement that the model satisfy elementary system characteristics. Among these are satisfaction of system identities, variables uniquely defined, consistency with known laws, etc. Also classified here are basic tests to insure that behavioral modes of the model correspond with real world behavior. Identities that exist in the real system must be modeled and simulated as identities. If the change of a parameter in a real system would change

an output variable, then the same direction of change should occur in the simulation model. If the real world system is stable under certain conditions, then the simulation model must be stable as well. Varying model parameters to generate alternative output dynamics, sensitivity testing of parameters, multiple input condition sets, and hand calculation are all means of determining logical consistency in a simulation model.

Examples illustrating logical consistency in six areas will be described here. These will concern:

1. stability of the simulation approximations by tests of DT size
2. verification of population identities
3. verification of feed allocation and feed stock consumption identities
4. verification of financial identities
5. exploration of parameter values controlling forage digestibility
6. exploration of parameter values controlling forage growth.

These examples will constitute partial evidence of the validity of the simulation model developed to describe a beef cattle enterprise.

An important characteristic of the simulation model is stability with respect to the DT step size used in the time simulation. The following section of this chapter will present the results of two tests of the simulation model's stability with respect to DT size. The approximations that are made in the differential equations of the population model to make them solvable in the computer via difference equations are directly related to the size of the DT step increment selected. Theory indicates that the errors of approximation should

tend toward zero as DT tends toward zero. First, during the early development of the demographic model five different step sizes were investigated to use in selecting the most appropriate DT step. Second, an exhaustive comparison of two runs of the most recent version of the simulation models was made using different DT sizes. These two examples will demonstrate that the DT step size selected for use is sufficiently accurate and need not be reduced to attempt greater accuracy.

An early version of the demography component HDMOG4, referred to as HDMOG3, was tested with five DT step sizes; the sizes tested were 0.01, 0.02, 0.03, 0.04, and 0.05 years. Three points in the simulated time output printing were selected for analysis; these times were 0.15, 0.50, and 1.0 years. Time equal to 0.15 corresponds to the most common value printed before the run using a DT value of 0.01 was prematurely aborted. Time equal to 0.50 corresponds to the point in the simulation horizon where maximum population was achieved. Time equal to 1.0 corresponds to the final time value. Table 6.1 presents the results of these simulation runs in terms of the total herd population at these three specified times for the five DT sizes investigated. Examination of these results shows that there is very little difference in the population values obtained for any of the DT sizes investigated. Therefore, to economize in the use of computer execution time, the size of 0.05 years was selected for use in this simulation model.

Table 6.1 Total Herd Population at Selected Points in Time Versus DT Step Size

DT size	T = 0.15	T = 0.50	T = 1.00
0.05	215.17	349.43	243.31
0.04	216.15	347.94	242.65
0.03	215.17	349.35	243.40
0.02	216.30	352.01	244.98
0.01	215.17	--	--

An attempt at validation of the population demography component is important because of the central position held by this part of the model. An identity exists in the demographic equations which will be exploited in this section to verify that the demographic component does perform correctly. By definition,

net population change = births - deaths - sales + purchases (6.2.1)

over any time interval, where each of these are quantities not rates. This equation may be solved for the variable, deaths, and this new equation used to compute deaths in each time interval. These death values computed from computer run output printing will be compared with the death values computed using the theoretical death rates assumed to apply over time.

Equation 6.2.1 can be solved for the variable, deaths, and transferred into the proper variable names as given in section V.9, with the following result:

$$\text{deaths}\Big|_{t}^{t+dt} = \text{SUBPOP}_{71}(t+DT) + \text{SUBPOP}_{81}(t+dt) + \sum_{i=1}^{9} \text{APUR}_i(t+dt)$$

$$- \sum_{i=1}^{9} \text{ASALES}_i(t+dt) + \sum_{i=1}^{9} [\text{POP}_i(t) - \text{POP}_i(t+dt)] \quad (6.2.2)$$

where:

$\text{deaths}\Big|_{t}^{t+dt}$ = total herd deaths over the time interval (t,t+dt)

$\text{SUBPOP}_{71}(t+dt)$ = male calf births over the interval (t,t+dt)

$\text{SUBPOP}_{81}(t+dt)$ = female calf births over the interval (t,t+dt)

$$\text{APUR}_i(t+dt) = \begin{cases} 0, & \text{if } \text{ADDRT}_i(t) \leq 0 \\ \text{ADDRT}_i(t)*\text{DT}, & \text{otherwise} \end{cases}$$

= animals purchased for cohort i during the time interval (t,t+dt)

$\text{ASALES}_i(t)$ = animals sold from cohort i during the time interval

$\text{POP}_i(t)$ = population of the i^{th} cohort at time t.

The theoretical deaths that should occur over the time interval (t,t+dt) are determined by the individual cohort death rates and the cohort populations at time t. The death rates are constant over time and are specified as data entries in the simulation model initialization phase. Therefore, deaths should follow the following theoretical relationship:

$$\text{deaths}\Big|_{t}^{t+dt} = \text{DT}* \sum_{i=1}^{9} \text{POP}_i(t)*\text{DR}_i \quad (6.2.3)$$

where:

$\text{deaths}\Big|_{t}^{t+dt}$ = total herd deaths over the time interval (t,t+dt)

DR_i = annual death rate for cohort i.

These two equations will be used to compute the simulated value and the theoretical value of deaths compared for a typical run of simulation model over the interval (0,0.35) in DT increments of 0.05 in Table 6.2.

Table 6.2 Comparison of Computed(Corrected) and Theoretical Herd Deaths Over Time

t	sim. deaths $\Big\|_{t}^{t+dt}$	theo. deaths $\Big\|_{t}^{t+dt}$	error
0.00	0.424 (0.325)	0.325	0.099 (0.000)
0.05	0.419 (0.320)	0.308	0.111 (0.012)
0.10	0.422 (0.323)	0.297	0.125 (0.026)
0.15	0.844 (0.745)	0.692	0.152 (0.053)
0.20	1.020 (0.921)	0.886	0.134 (0.035)
0.25	1.089 (0.990)	0.921	0.168 (0.069)
0.30	1.063 (0.964)	0.956	0.107 (0.003)
0.35	1.083 (0.984)	0.953	0.130 (0.031)
interval totals	6.364 (5.562)	5.336	1.028 (0.226)
interval error	---	---	19% (4%)

The results presented in Table 6.2 indicate a consistently high estimation of death rates by the death rate equation 6.2.2, as compared to the theoretical values computed using equation 6.2.3. Since equation 6.2.2 is subject to errors from many sources, it is not surprising that there is some error present. A factor contributing to these consistently high estimates is the way in which the variable $ASALES_i(t)$ is computed. This variable is the number of cattle sold in the time increment (t-dt, t) from cohort i. As explained in section V.6, this variable is integerized so as to give even integer numbers of animals sold from each herd cohort. This integerization process loses the true value, but the rationale is that the errors of integerizing will sum to zero over the entire herd. In the results analyzed in Table 6.2, the $ASALES_4(t)$ value is always zero, but it is zero because the integerizing process makes it zero. Without such integerizing there would be a small positive value for each $ASALES_4(t)$ through time. When this factor is included in the error determination, the resulting percentage of error in accumulated deaths over the time span (0,.35) drops from 19% to 4%. In table 6.2 the values in parentheses indicate the value of simulated deaths and the error of this value, taking into account the integerization source of error.

The sample output analyzed here verifies that the demographic component is performing as it should. The population identity relating births, deaths, sales, and purchases has been shown to be simulated quite closely to the theoretical values. When the errors are viewed in terms of their magnitude compared to the total herd population at any time, then such errors are extremely small (on the order of 0.2%). The only significant effect of the error is a very slightly smaller herd population than would be predicted if the theoretical death rates held true. A slight error is made in the financial component by using this integerization process, but it is not significant.

A second area where identities may be used to determine proper functioning of the model is in feed allocations and feed stock consumption. Management allocates feed to the cohorts on the basis of specified desired levels of TDN to be delivered per animal per day. Depending on the current TDN value of each feed stock and the desired proportion of the TDN allocation to come from each feed stock, the physical quantities allocated are determined. $CNCAL_i(t)$ and $FEEDAL_i(t)$ are the quantities of concentrate and roughage allocated to cohort i, respectively. These allocations are in units of kg/DT. Equation 6.2.4 represents the total feed (in kg/DT) allocated to the herd.

$$ALLOCATION_1 = \sum_{i=1}^{9} [CNCAL_i(t) + FEEDAL_i(t)] \tag{6.2.4}$$

The mix of the TDN allocation to each cohort from feed stock n and the population of each cohort result in the quantity of feed stock n fed in the current time increment--$STKFED_n(t)$. Equation 6.2.5 represents the total quantity of feed stocks allocated to the herd.

$$ALLOCATION_2 = \sum_{n=1}^{NSTOCK} STKFED_n(t) \tag{6.2.5}$$

Logical consistency requires that these allocations be equal to one another; that is, the allocation in terms of cohort allocations must be the same as the allocation in terms of feed stocks used for feeding.

A typical model run from initialization (t=0.0) to the spring decision point (t=.25) was selected for analysis to veryify this feed stock identity. Table 6.3 presents the results of output printing over a time interval of 4 DT's. The allocations according to

equations 6.2.4 and 6.2.5 are given along with the difference between them. Even cursory examination will show excellent agreement between these two forms of feed stock allocations.

Table 6.3 Feed Stock Allocations

t	$ALLOCATION_1$	$ALLOCATION_2$	$DIFFERENCE_{1-2}$
0.05	54,037.3	54,039	-1.7
0.10	54,552.4	54,555	-2.6
0.15	54,742.0	54,742	---
0.20	61,192.3	61,192	0.3

Source: Computer Printout Number MV57864

A second feed stock identity used to verify that the accounting process of subroutine FEEDS works properly is the basic individual feed stock balance equation.

$$FSTOCK_n(t) = FSTOCK_n(t-dt) - CSALES_n(t) - STKFED_n(t) - STKLOS_n(t) + CROP_{n1}(t) + STKPUR_n(t) \qquad (6.2.6)$$

Briefly stated, present feed stock level equals former feed stock level minus sales, quantity fed to cattle, losses and plus crop production and stock purchases. Detailed explanation can be found in section V.3. This equation must be followed for the feed stock component of the simulation model to be working correctly.

By drawing on the same printout used above, the validity of the feed stock component can be demonstrated. A single feed stock was

selected for study and followed through the same time interval used above; i.e., (0.0,0.25). Table 6.4 presents the results of the computer printout and the calculated value of $FSTOCK_n(t)$ using equation 6.2.6. $FSTOCK_p$ represents the simulated value printed, while $FSTOCK_c$ represents the calculated value. Excellent agreement was found between these two values at each time point. The simulation model component FEEDS does work properly.

A third testing point for logical consistency in the feed allocation and feed stock consumption area involves comparison of the desired TDN to be fed to the herd and the TDN actually fed. Allocation of TDN is controlled by the user through the values of $CATTIN_{i1\ell}(t)$, $CATTIN_{i2\ell}(t)$, and $FPLANS_\ell$. These are the kg TDN to be delivered to each member of cohort i from concentrates per day, the kg TDN to be delivered to each member of cohort i from roughage per day, and the times at which feed plan ℓ is to be completed, respectively. Desired TDN delivery is then

$$\text{DESIRED TDN} = \text{DAYS}*\sum_{i=1}^{9} POP_i(t)*[CATTIN_{i1\ell}(t) + CATTIN_{i2\ell}(t)] \quad (6.2.7)$$

Actual TDN delivered to the herd is simply the product of each feed stock delivered times its TDN value, summed over all feed stocks. This gives

$$\text{ACTUAL TDN} = \sum_{n=1}^{NSTOCK} FQUAL_n(t)*STKFED_n(t) \quad (6.2.8)$$

An example run for a single DT time increment is presented in Table 6.5; this is the same run analyzed previously. There the population and desired feed levels are reported for each herd cohort as

Table 6.4 Feed Stock Values Compared Over Time

t	0.00	0.05	0.10	0.15	0.20	0.25
$FSTOCK_p$	225000	222750	206701	190478	174191	157898
CSALES	0	0	0	0	0	--
STKPUR	0	0	0	0	0	--
STKFED	0	15937	16120	16191	16206	--
CROP	0	0	0	0	0	--
STKLOS	2250	111	103	95	87	--
$FSTOCK_c$	--	222750	206702	190478	174192	157898
$error_{c-p}$	--	0	1	0	1	0

source--computer run MV57864

Table 6.5 Sample Run of Feed Stock Use and Desired Allocation

i/n	$POP_i(t)$	$CATTIN_{i11}(t)$	$CATTIN_{i21}(t)$	$FQUAL_n(t)$	$STKFED_n(t)$
1	228.800	5.0	1.0	0.49	15,937
2	39.939	4.0	1.0	0.76	7,425
3	---	4.0	1.0	0.83	---
4	19.837	6.0	2.0	0.46	16,977
5	---	5.0	1.0	0.76	13,700
6	---	5.0	1.0	---	---
7	---	---	---		
8	---	---	---		
9	---	4.0	1.0		

Source: Computer Run MV57864

DESIRED TDN = 31,594.3 kg/DT

ACTUAL TDN = 31,673.5 kg/DT

error = +0.25%

well as the quantity fed and quality of each feed stock. Only a very slight difference exists between actual and desired TDN; this further indicates logical consistency.

A final area where logical consistency can be verified through identities is within the financial component. Variable values are computed within four subroutines specialized in a particular area, such as production costs, and are brought together to form higher level variable values, such as gross profit, in subroutine FINANC. Three equations will be used to verify that the financial component is properly bringing costs, revenues, depreciation, debt repayment, and taxes into computation of gross profit per period, annual gross profit, and discounted gross profit at final project termination correctly.

The fundamental equation of interest is that one determining gross profit per DT time period. This is

$$TPGRP(t) = AREV_{10}(t) + CREV_4(t) - ACOST_{NACOST+1}(t) - CCOST_{NCCOST+1}(t) - CAPTL_5(t) \quad (6.2.9)$$

In this equation gross profits in the current time increment are the animal and crop revenues minus the animal and crop production costs minus debt servicing. This gross profit figure contributes to taxable income for the current year, as do depreciation charges. This rationale gives a second equation:

$$TAXINC(t) = TAXINC(t-dt) + TPGRP(t) - CAPTL_4(t) \quad (6.2.10)$$

where TAXINC(t) is the taxable income earned in the calendar year to date. Finally, at the conclusion of the simulation time horizon, the discounted annual gross profit figures are used to compute the

discounted present value of this profit stream over time. Thus

$$TAGRP_m(t) = TAGRP_m(t) + TPGRP(t) \tag{6.2.11}$$

$$PRV_{1\ell} = \sum_{m=1}^{MYEAR} \frac{TAGRP_m}{(1+DISC_\ell)^m} \tag{6.2.12}$$

For a detailed explanation of these equations and individual variable definitions, see sections 6 and 9 of Chapter V.

A test case used to analyze whether the financial component is working properly is represented in tabular form in Table 6.6. A non-interactive management algorithm was used in this run to speed up the simulation process; this allowed a run over a one-year time horizon in a single model run. A DT time increment of 0.03846 (two weeks) gives 26 time increments over the time interval (0.0,1.0). Table 6.6 lists all financial variables needed to compute equations 6.2.9-12 by hand.

Computing TPGRP(t), as given by equation 6.2.9, and comparing it with the simulated values given in Table 6.6, reveals no instances where the computed value and the simulated value differ by more than one cent. This excellent agreement indicates that TPGRP(t) is simulated correctly from the constituent elements of equation 6.2.9. Table 6.7 summarizes the comparison of the simulated and calculated values of $TAGRP_m(t)$, TAXINC(t), and PRV_{1i} through PRV_{16}.

Examination of Table 6.7 will reveal excellent agreement between the printed values obtained from the simulation and the calculated values determined from the elements of the equations. Again, the conclusion is reached that the financial component is properly

Table 6.6 Selected Financial Variables Over a Simulation Time Horizon of One Year

Time	$AREV_{10}$	$CREV_4$	$ACOST_{NACOST+1}$	$CCOST_{NCCOST+1}$	$CAPTL_5$	$CAPTL_4$	TPGRP	TAXINC
0.038	198.00	0.00	390.35	0.00	1288.41	0.00	-1480.76	-1480.76
0.077	198.00	0.00	389.05	0.00	1284.86	0.00	-1475.91	-2956.66
0.115	198.00	0.00	428.58	0.00	1281.31	0.00	-1511.89	-4468.55
0.154	198.00	0.00	457.00	0.00	1277.76	0.00	-1536.76	-6005.31
0.192	198.00	0.00	507.75	0.00	1274.21	0.00	-1583.96	-7589.28
0.231	198.00	0.00	499.66	0.00	1270.66	0.00	-1572.32	-9161.60
0.269	198.00	0.00	1749.70	0.00	1267.11	0.00	-2818.81	-11980.41
0.308	198.00	0.00	226.14	0.00	1263.56	10750.00	-1291.70	-24022.10
0.346	198.00	0.00	224.73	0.00	1260.01	0.00	-1286.74	-25308.84
0.385	198.00	0.00	224.64	0.00	1256.46	0.00	-1283.10	-26591.95
0.423	198.00	0.00	224.55	0.00	1252.91	0.00	-1279.46	-27871.41
0.462	198.00	0.00	1590.90	0.00	1249.36	0.00	-2642.26	-30513.66
0.500	198.00	0.00	1653.77	0.00	1245.81	0.00	-2701.58	-33215.25

Table 6.6 Cont'd

Time	$AREV_{10}$	$CREV_4$	$ACOST_{NACOST+1}$	$CCOST_{NCCOST+1}$	$CAPTL_5$	$CAPTL_4$	TPGRP	TAXINC
0.538	198.00	0.00	1580.56	0.00	1242.26	0.00	-2624.82	-35840.07
0.577	198.00	0.00	1575.41	0.00	1238.71	0.00	-2616.12	-38456.19
0.615	198.00	0.00	1570.26	0.00	1235.16	0.00	-2607.42	-41063.60
0.654	198.00	0.00	1565.11	0.00	1231.61	0.00	-2598.72	-43662.33
0.692	14683.86	0.00	993.68	1638.00	1228.06	0.00	10824.13	-32838.20
0.731	198.00	0.00	216.82	0.00	1224.51	0.00	-1243.33	-34081.53
0.769	5148.00	0.00	227.02	273.00	1220.96	0.00	3427.02	-30654.51
0.808	198.00	90011.77	2392.75	136.50	1217.41	0.00	86463.12	55808.60
0.846	198.00	0.00	409.79	0.00	1213.86	0.00	-1425.65	54382.96
0.885	198.00	0.00	408.46	0.00	1210.31	0.00	-1420.77	52962.19
0.923	198.00	0.00	407.14	0.00	1206.76	0.00	-1415.90	51546.28
0.962	198.00	0.00	405.83	0.00	1203.21	0.00	-1411.04	50135.25
1.000	198.00	0.00	404.51	0.00	1199.66	0.00	-1406.17	48729.07

Table 6.7 Comparison of Calculated and Simulated Values of Financial Variables

Variable	Computed	Simulated	Difference
TAXINC(t_f)	$48729.08	$48729.07	$-0.01
$TAGRP_1$	59479.08	59479.07	-0.01
PRV_{11}*	59479.08	59479.08	-0.01
PRV_{12}	58312.82	58312.82	0
PRV_{13}	57191.42	57191.42	0
PRV_{14}	56112.34	56112.33	-0.01
PRV_{15}	55073.22	55073.22	0

* the discount rates used for PRV_{11} through PRV_{15} are 0.0, 0.02, 0.04, 0.06, and 0.08, respectively

simulating the revenues and costs involved in the enterprise's operation.

A final note concerning validation of the financial component directs the reader's attention to Table 6.6. The typical pattern of highly irregular cash flows from cattle and crop sales are well illustrated in this run. The effect on gross profit in each time increment is just as mentioned previously in this thesis--a cattle enterprise is characterized by negative cash inflows, punctuated occasionally by very heavy positive inflows. Even though the overall profit earned in this model run is positive, there are only three DT time increments where positive cash inflows have occurred. These times are 0.692, 0.769, and 0.808. These times correspond to sales of weaned calves, sales of culled cows, and sales of forage harvested beyond projected herd needs for the winter. The animal production costs reported in the $ACOST_{NACOST+1}(t)$ column are indicative of the many different events occurring through the course of the year requiring different levels of resource consumption and, hence, overall production cost.

Proper determination of forage digestibilities is an important aspect of the validation of the forage growth component, because of the vital influence digestibilities have in the nutrient impact component. The initial modeling attempt for this component, following Anway [2], failed to properly predict forage digestibilities. Some reasons for this failure are the lack of a factor relating forage density in terms of quantity of forage per animal grazing to digestibility and that the curves represented by the arrays BDGEST and QUALTY were not well specified.

Digestibility of forage in each land parcel is determined bv equation 6.2.13. It is the product of the basic digestibility, the seasonal adjustment factor, and the forage density adjustment factor.

$$DIGEST_n(t) = BASEDG_n(t)*FRQUAL(t)*FDENSE_n(t) \quad (6.2.13)$$

Each of these three factors is determined by linear interpolation between data values to obtain the proper factor value corresponding to the argument value. A complete discussion of this formulation and the determination of the function value corresponding to the input argument can be found in section V.2.

Figures 6.1 and 6.2 depict several trial sets of values for the elements of the arrays BDGEST and QUALTY used in the determination of $BASEDG_n(t)$ and FRQUAL(t), respectively. Table 6.8 lists the results of nine runs investigating the effect of alternative trial shapes of the curves defined by the elements of the arrays BDGEST and QUALTY. Run 1 is the result of the original curves as taken from Parton and Marshall [40], Sauer [47], and Anway [2]. Runs 2 through 6 investigate alternative shapes of these curves as pictured in Figures 6.1 and 6.2. Runs 7 through 9 illustrate the effect of alternative weather patterns on the original model (run 1) and the best model (run 6). All runs have zero-level mechanical harvesting and grazing to remove these influences from the range of digestibilities produced by the natural response of the forage growth component to climatic input factors.

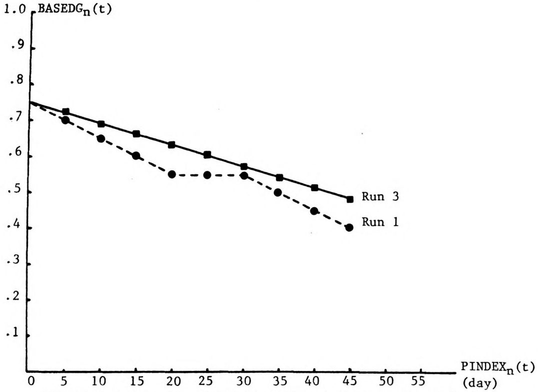

Figure 6.1 Base digestibility values versus an age index.

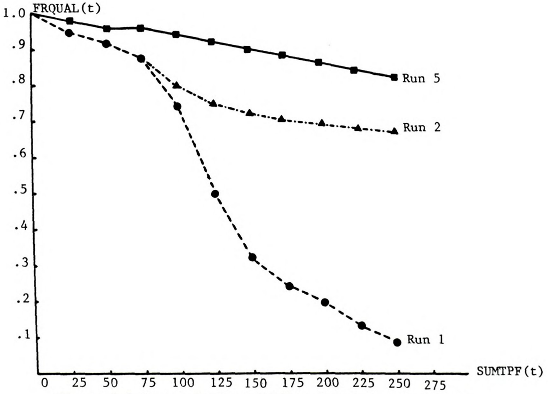

Figure 6.2 Seasonal digestibility factor versus season.

Table 6.8 Forage Digestibility Factors Investigated to Obtain an Improved Digestibility Range

Run	Definition	Digestibility Range
1	original	29 - 46 %
2	first QUALTY set	32 - 46
3	first BDGEST set	35 - 51
4	both 2 and 3	38 - 51
5	second QUALTY set	38 - 51
6	both 3 and 5	45 - 54
7	1 and first of climate changes	28 - 53
8	6 and first of climate changes	45 - 56
9	6 and second of climate changes	45 - 51

Runs 2, 3, 4, and 5 represent intermediate improvements over the base run. A better run than all of these is run 6, which incorporates the changes made in run 3 and run 5. Forage digestibilities ranged from 45 to 54% TDN in this run. This range closely corresponds to digestibilities of forage grasses obtained through field trials and experimental observation in temperate climates [11, 14, 15]. If the forage material is alfalfa or other high-energy plant species, then this range in digestibilities is excessively small. A scaling factor to adjust forage digestibility base levels might be adapted to provide a more flexible tool for evaluating different grazing environments. This improvement will be left for future development.

Runs 7, 8, and 9 represent an attempt to determine the responsiveness of the forage growth model to alternative climatic patterns. Logical consistency requires that forage growth and digestibility have some degree of response to levels of solar radiation and rainfall. Run 7 evaluates the effect of a first alternative weather pattern on the "best" model, as determined in run 6. Run 9 evaluates yet a second alternative weather pattern on the "best" model. Table 6.9 indicates the weather conditions, range of forage digestibility, and forage production for runs 1, 6, 7, 8, and 9. Runs 1 and 7 should be compared to each other, as should the group of runs 6, 8, and 9.

Comparison of runs 1 and 7 in Table 6.9 reveals that under conditions of reduced rainfall and reduced solar radiation that forage production has dropped significantly from run 1 to run 7.

Table 6.9 Weather Effects on Forage Growth and Forage Digestibility

run / variable	1	7	6	8	9
average solar radiation(ly)	221	186	221	186	186
average rain-fall(cm/day)	0.84	0.69	0.84	0.69	0.70
average tem-perature(°C)	8.5	8.5	8.5	8.5	8.5
digestibility range(%)	29-51	28-53	45-54	45-56	45-51
total forage production (kg)	4449	3813	4449	3813	4418

The range of digestibilities has also broadened marginally. These effects are what would be expected, since forage growth is primarily related to solar radiation levels. In fact, the percentage of reduction in forage growth is roughly midway between the percentage of reduction in solar radiation and the percentage of reduction in rainfall.

Comparison of runs 6 and 8 in Table 6.9 reveals that the shift from the standard climatic variable pattern shared by runs 1 through 6 to the climatic variable pattern shared by runs 7 and 8 has a very similar effect to that reviewed above for runs 1 and 7. Again, the range of forage digestibilities has broadened slightly. The same drop in forage production has occurred, becaase the growth prediction aspects of all nine of these runs are common.

Run 9 shares the same factors determining forage digestibility with runs 6 and 8 but has yet a different weather pattern. The average values of the climatic patterns listed for runs 8 and 9 are nearly the same, but the pattern across the year (and especially the growing season) is different. This difference is all important, as the results of run 9 indicate. Run 9 has only a slightly decreased level of forage growth from run 6, whereas run 8 had quite a large drop. Forage digestibilities have also decreased in the range experienced in run 9, compared to an increase in range in run 9, using run 6 as the basis for comparison. This illustrates the obvious fact that the distribution of rainfall is as important to plant growth as is the overall level of annual rainfall.

Forage growth is sensitive to a number of parameters in the growth model, as explained in section V.2. The original parameter values result in a split between greenery and root storage, which appears to favor storage excessively. The following paragraphs will discuss some sensitivity studies of the forage growth component to obtain an improved proportioning of energy transformation between greenery, growth, and root storage.

Five parameters, which are used in a total of two equations, were tested singly and together in an effort to achieve a more realistic forage growth characteristic. Equation 6.2.14 indicates the return flow rate of greenery growth from energy storage in the roots to greenery.

$$F_n(t) = PAR1*ROOT_n(t)*e^{-GRN_n(t)/PAR2*LAND_n} \qquad (6.2.14)$$

Equation 6.2.15 determines the proportion of the overall plant growth rate being apportioned to root storage, as opposed to greenery growth.

$$ZX3_n(t) = PAR3 + PAR4*\left(1.0 - e^{-PAR5*GRN_n(t)/LAND_n}\right) \qquad (6.2.15)$$

Table 6.10 lists the results obtained from 14 runs testing various parameter values in an attempt to achieve an increased proportion of total growth directed to greenery instead of to root storage. The run numbering used here continues that started in the runs listed in Table 6.8.

Runs 10 through 22 represent changes in the noted parameter(s) from the base values listed for run 6. Run 6 is the same as the run 6 referred to in Table 6.8. It includes the original parameter values

Table 6.10 Sensitivity Testing of the Parameters of the Forage Growth Model

Run	Description	Forage(kg/hec)	Roots(kg/hec)
6	base values	4449	3221
10	PAR5=0.0008	4595	3143
11	PAR5=0.0005	4926	2919
12	PAR5=0.0003	5280	2614
13	run 12, PAR4=.20	5463	2446
14	run 12, PAR4=.20	5651	2272
15	run 12, PAR4=.15	5844	2093
16	run 15, PAR1=.15	5915	2108
17	run 15, PAR1=.20	5956	2116
18	run 15, PAR2=400.	6033	2090
19*	run 18, PAR1=.20	6402	2212
20	run 18, PAR3=.15	6452	1764
21	run 18, PAR3=.10	6886	1426
22*	run 21, PAR1=.15	7035	1457

* an unstable parameter set which caused the quantity of roots per hectare to approach zero

obtained from the first developers of this model form (Parton and Marshall, Sauer, and Anway) and the improved digestibility factor relationships described earlier in this chapter. The goal of these investigations was to obtain improved parameter values, which would decrease the quantity of root storage, while increasing the quantity of greenery growth. The quantity of forage and root storage reported in Table 6.10 are the average kilograms per hectare existing at the conclusion of the growing season. No animal or mechanical harvesting was allowed in these runs.

Runs 10, 11, and 12 evaluated successively smaller values of PAR5 from its base value of 0.001. The effect of this parameter is to decrease the weight of the current greenery in the equation controlling the split of growth going to root storage and growth going to greenery. The observed effect was, in fact, successively higher forage levels and lower root values.

Runs 13, 14, and 15 evaluated successively smaller levels of PAR4 from its base value of 0.30. The effect of this parameter is to control the maximum fraction of photosynthetically converted growth which is directed toward root storage as opposed to greenery. The result of these decreases in the value of PAR4 were increased forage growth and decreased root storage, as predicted by the equations themselves. These three runs were performed while holding PAR5 at the value of 0.003, so the base level of comparison for them is run 2 rather than run 6.

Runs 16 and 17 are unprofitable attempts at departures from run 15, with increased levels of parameter PAR1. Rather than decreased root storage, as might be expected, there were very slight increases in the season end figures. Run 19 evaluated the addition of PAR2 = 400, while retaining the other values of run 17. It results in unacceptable behavior, in which root storage quantities drop from their initial spring level to zero. All three of these runs are actually unreasonable, since the average root storage quantity drops nearly to zero in runs 16 and 17. Parameter PAR1 is quite sensitive in early forage growth stages, and any levels higher than the base level of 0.10 result in unrealistic model behavior. For this reason, PAR1 = 0.10 will be retained as an element of all parameter sets.

Run 18 evaluates the effect of PAR2 increases on the best run obtained so far; i.e., run 15. Increasing PAR2 from its base level of 200 to 400, decreases the weight given to forage greenery levels in predicting energy transfer from roots to greenery. As expected, increased forage growth and decreased root storage result.

Runs 20 and 21 evaluate the effect of decreased levels of parameter PAR3 from the basis of run 18. PAR3 controls the minimum level of the proportion of photosynthetically predicted storage going to roots. Decreases from 0.20 to 0.15 and 0.10 result in significantly increased forage growth and decreased root storage.

Run 22 again attempts decreases in the value of parameter PAR1, with the same unstable results as in runs 16, 17, and 19. This reinforces the conclusion that paramter PAR1 should be maintained at a value of 0.10, regardless of other parameter values. To do otherwise allows excessively high transfer from roots to greenery, resulting in the quantity of root storage being driven to zero. This cannot be permitted to happen.

As a result of these investigations, the parameter set evaluated in run 21 was adopted as the new basis set to be used in any subsequesnt use of the model. This set includes PAR1 = 1.10, PAR2 = 400, PAR3 = 0.10, PAR4 = 0.15, PAR5 = 0.003, and PAR6 = 15.0. End-of-the-growth-season forage quantities are 6,886 kg/hec, while root storage quantities are 1,426 kg/hec. Figure 6.3 [3,20,40] plots the dynamic growth path followed by forage greenery in run 21, along with several wide-ranging indications of relative forage growth. Goudriaan [20] reports two growth patterns very different from the growth path followed by run 21. Simulation models were developed for each of these curves, which duplicated the observed data quite closely. The range of forage growth values reported by Parton and Marshall [40] represent outcomes of alternative climatic conditions for their grassland model. Unfortunately, the weather variables they used were quite different from those resulting in run 21; in fact, the seasonal rainfall was much less than that encountered in run 21, which is reflected in the much slower growth levels experienced. The range of growth values reported by Baker [3] are indicative of Venezuelan conditions. This range completely brackets the result of run 21. The various references cited here, while unable to verify that the forage growth pattern is accurate, are indicative that the proper range of response has been achieved with the parameter set used in run 21.

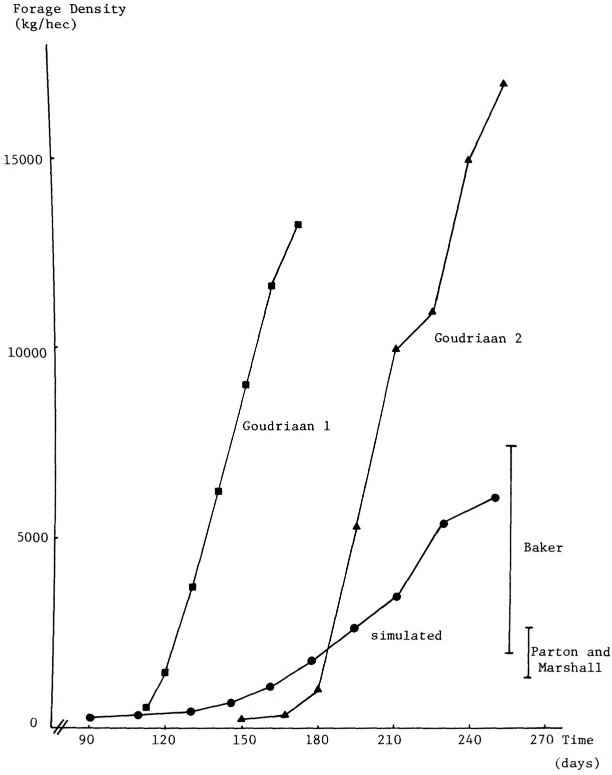

Figure 6.3 Plant densities over the growing season

Tracking Historical Data

An important part of the validation process is the tracking of historical data by the simulation model. This ability (on the part of the model) is a significant achievement, which contributes substantially to confidence in the simulation model. Demonstration of the model's ability to track multiple historical time series is further evidence (and of a higher order than logical consistency tests) that the model really does represent the real system it is supposed to represent. The following paragraphs will clarify the process of tracking historical information, discuss some potential problems and difficulties, explain the relationship between tracking the past and predicting the future, and explain the historical tracking performed here.

The purpose of having a model track historical time series is, except for academic studies into past behavior, determination of the model's valid representation of the structural relationships over the period in question, with the common sense feeling that this validates the model for the future as well. Obviously this linkage of the past and the future supposes that the relationships between variables is constant through time. In other words, the system has not changed. We can see immediately that this supposition is questionable as a general rule of behavior. We need, therefore, assurance that the past and the future systems are the same, if we are to trust a validated model of the past in the future.

When we are satisfied that tracking historical information is a valuable thing to accomplish, how does one go about it? How many

time series should be used? What means of reconciling deviations between simulated values and historical values should be used? How closely must the simulation series track the historical series to be proclaimed satisfactory? What criteria can be used to distinguish between time series which are "important" and those which are "unimportant?" Of these many questions, little of a definitive nature can be said. Current practice leans heavily to such measures as sum of squares and total sum of squares of the deviations between historical and simulated series as indicators of disagreement between data and model.[3] Gilmour [18] reviews many statistical techniques which can be used in principle but offers little direction about criteria for choosing among them for specific examples. This is an area needing research and attention as simulation models become more widely used and more important to decision-making at both the micro and macro economic levels.

Supposing that one had available relevant time series and an appropriate measure(s) of error, there remains the thorny problem of fine tuning the model to reduce this error measure. In the complicated simulation models now being constructed, there are extremely large numbers of parameters which are candidates for change to make the model perform better. No general advice is possible here, as every model is unique at this point. It takes a deep familiarity with, and intuition about, the model to select parameters for adjustment to

[3] G. L. Johnson, G. E. Rossmiller, and T. W. Carroll, "Problems of Verification and Validation of Large-Scale Simulation Models," Statistics Seminar, Michigan State University, January 20, 1976.

improve the error measure. This is a time-consuming problem which should be viewed in a long-term perspective as an ongoing process.

This brings one up to the point where one must realize that models are rarely ever clearly right or wrong. They have gradations of rightness and wrongness which can be changed over time through improved parameters, improved data to track against, and improved structural relationships. Models (in the positive sense) are built to predict the future, not to duplicate the past. A model must be installed and used and then trusted to greater degrees as its performance improves. The "new" historical information recorded as time passes becomes data which can be tracked against, even if there were no "old" historical data in the first place. If the model structure is adequate, the passage of time affords the user/developer the opportunity to track against valid time series to fine tune the model parameters. The model will gradually improve, and confidence in its predictions will then increase. Eventually good models will be trusted and used because of their great ability; bad models will be either made good or shelved.

The simulation model of a beef cattle enterprise developed in this thesis has no historical data to track against. This is a weakness which will inhibit verification and validation of the model, but not fatally so. The very extensive work on logical consistency reported earlier in this chapter is a partial substitute for this lack of data. The use of experts to "eyeball" model results is an additional step in the validation process which can be relied upon to complete the determination of validation for this model.

Expert "Eyeballing"

As the third step in the hierarchy of validation procedures, the satisfaction of expert "eyeballing" is more sophisticated than logical consistency and tracking historical data. At the same time this step is also less rigorous than the first two. It is quite possible for a model to have cleared the first phases of validation and still be found wanting by experts of the system's behavior. Logical consistency and tracking of historical data are levels of validation which do not require extensive knowledge of the system under study. A model can still contain errors of significance which can only be detected by having an expert review the model output for certain initial conditions and control modes. The intuitive knowledge of the expert is highly useful at this point because it is this source which can say, "This just doesn't look right!" More detailed study of such problem areas can reveal whether the model is correctly simulating the real system that it is supposed to represent. If found wanting, then the model can be improved and returned to the expert for appraisal; this iterative process of review may cycle several times before an acceptable model emerges validated.

An example of expert "eyeballing" discovering modeling misbehavior is the case of the rates of weight gain for calves. Well into the validation process, the discovery was made (by an expert in animal husbandry) that the predictions of male and female calf weight gains were inconsistent with common experience. Figure 6.4 illustrates

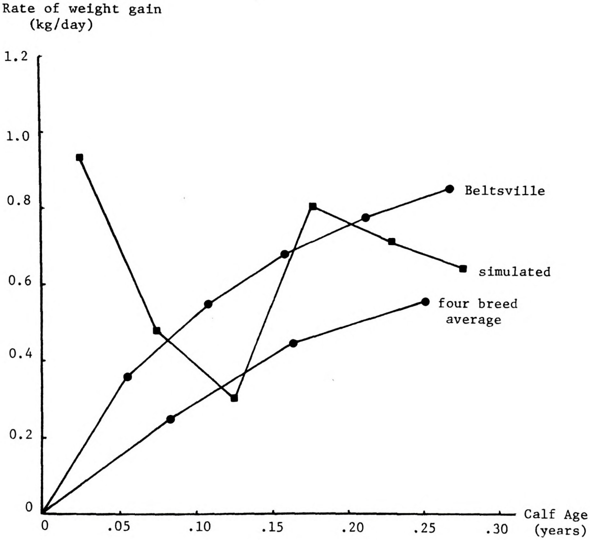

Figure 6.4 Rate of weight gain of male calf animals versus age

the pattern of weight gains produced by the model and two typical weight gain patterns.[4]

Examination of Figure 6.4 shows that the modeling error is the pattern of weight gains starting at excessively high levels for very young calves and decreasing with age. The real behavior is to have low rates of weight gain initially, with subsequent increases as the calves grow older. Realization of this error resulted in a modification to one of the routines imbedded within subroutine NUTRN. Details of this final version can be found in Schuette[48].

A second example of the use of expert "eyeballing" of output results to determine model validity is given by a series of simulation runs exploring alternative grazing and harvesting policies for their effect on forage growth. This series of runs explores timing of forage harvest, intensity of grazing, and combined grazing/harvesting schemes for their effects on dynamic growth and total forage available for harvest. Additionally, the effect of weather differences on the effect of these policies is evaluated through use of second runs in many cases. Table 6.11 presents the results of 15 model runs reporting total forage harvestable with the described management action, and with no harvesting activity at all. The units reported are are kg forage harvested and harvestable per hectare, and kg TDN forage harvested and harvestable. The effects in terms of kg TDN/hec are more crucial to the impact on the cattle herd because TDN values change radically as new growth appears after harvesting actions.

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[4] USDA, Beltsville Growth Standards for Holstein Cattle, Technical Bulletin No. 1099, Washington, D. C., 1954, p. 5.

Table 6.11 Effect of Grazing and Harvesting Policies on Forage Growth and Obtainability

		Forage Quantity (kg/hec)			kg TDN/hec
Run	Description	Action	No Action	Difference	Difference
1	80% harvest at T = 0.4	5,790.02	6,886.34	-1,096.32	-454.22
2	80% harvest at T = 0.5	6,251.11	6,886.34	-635.23	-205.67
3	80% harvest at T = 0.6	6,175.32	6,886.34	-711.02	-298.79
4	80% harvest at T = 0.7	6,410.52	6,886.34	-475.82	-214.11
5	80% harvest at T = 0.4 and at T = 0.7	5,357.11	6,886.34	-1,529.23	-649.03
6	80% harvested at T = 0.4, T = 0.5, T = 0.6, T = 0.7	2,863.26	6,886.34	-4,023.08	-1,672.55
7	80% harvested at T = 0.4 and at T = 0.7, with different weather from run 5	3,827.04	5,831.44	-2,004.40	-862.87
8	80% harvested at T = 0.4, T = 0.5, T = 0.6, T = 0.7, with different weather from run 6	2,016.39	5,831.44	-3,815.05	-1,651.83
9	Animal grazing removal of 500 + 2,000T kg/day	This action is infeasible with season-long grazing.			
10	Animal grazing removal of 500 + 2,000T kg/day, with different weather from run 9	This action is infeasible with season-long grazing.			
11	Grazing 5.0 kg/hec-day	4,613.6	6,886.34	-2,272.74	-915.05
12	Grazing 5.0 kg/hec-day, with different weather from run 11	4,674.20	5,831.44	-1,157.24	-430.43
13	Grazing 5.0 kg/hec-day + 80% harvested at T = .4, with different weather from the base	This action is infeasible with season-long grazing.			
14	Grazing 5.0 kg/hec-day + 80% harvested at T = 0.5, with different weather from the base	2,381.81	5,831.44	-3,502.63	-1,446.27
15	Grazing 5.0 kg/hec-day + 80% harvested at T = 0.7, with different weather from the base	3,649.10	5,831.44	-2,182.34	-887.17

Runs 1, 2, 3, and 4 explore the effect of a single harvest removing 80% of the existing forage by weight at times 0.4, 0.5, 0.6, and 0.7, respectively. In terms of minimum effect on physical quantity potential harvestable (amount actually harvested and final forage value) run 4 is superior. In terms of TDN, run 2 is slightly less harmful than is run 4. In all cases the effect of harvesting is to reduce the quantity of potentially harvestable forage.

Runs 5 and 6 investigate multiple harvesting schemes, with the result that two harvests is superior to four but that both are worse than any of the single harvests evaluated in runs 1 through 4. Runs 7 and 8 duplicate the harvesting action of runs 5 and 6, respectively, but under somewhat less favorable weather conditions. The overall harvest possible using only a single end of the growth season harvest (T=0.75) drops from 6,886 kg/hec to 5,831 kg/hec simply because of weather differences. Run 7 turns out to be worse than run 5 in both physical effect and TDN effects, while run 8 is superior to run 6 in both physical and TDN effects. The overall average rainfall, average solar radiation, and average temperatures are important to growth as well as the distribution lying behind such averages. Distributional effects are surely responsible for the improvement of run 8 over run 6 in light of run 7 being inferior to run 5.

Runs 9 through 12 shift from forage harvest to cattle grazing. Runs 9 and 10 explore the consequences of a heavy grazing pressure on a land parcel of 100 hectares. In both the standard weather conditions (run 9) and less favorable weather conditions (run 10), the given rate of forage removal through grazing is untenable with season-long grazing. The pressure is so great that all forage is consumed. Figures 6.5 and 6.6 depict the dynamic forage levels which occur in runs 9 and 10, respectively, with grazing and without, for comparison purposes.

Runs 10 and 12 illustrate the effects of a successful level of grazing on forage production. Although this policy is successful in terms of being possible over the grazing season, the net effect of grazing is reduced forage production. This effect is quite sensitive to weather, as the difference between runs 11 and 12 indicates. Run 12 has an overall growth reduction of 1,054.9 kg/hec from basic weather conditions but a marginal increase in forage potential under the grazing policy tested. Figures 6.7 and 6.8 illustrate the dynamic pattern of forage growth in runs 11 and 12, respectively.

Runs 13, 14, and 15 illustrate the effects of combined grazing and harvesting policies. The grazing intensity remains constant at 5.0 kg/hec/day, while the timing of 80% harvesting shifts from 0.4 to 0.7. Figure 6.9 illustrates the dynamic effect of those policies on forage density. Run 13 is an untenable policy, as the early harvest combined with grazing pressure exhausts all plant material in midsummer. Runs 14 and 15 are feasible, but neither would be particularly profitable, since the quantity harvested during the growth season is not as large as the drop in the final density at T = 0.75.

The fifteen runs reported here present a picture of the current operating characteristics of the forage growth component, with

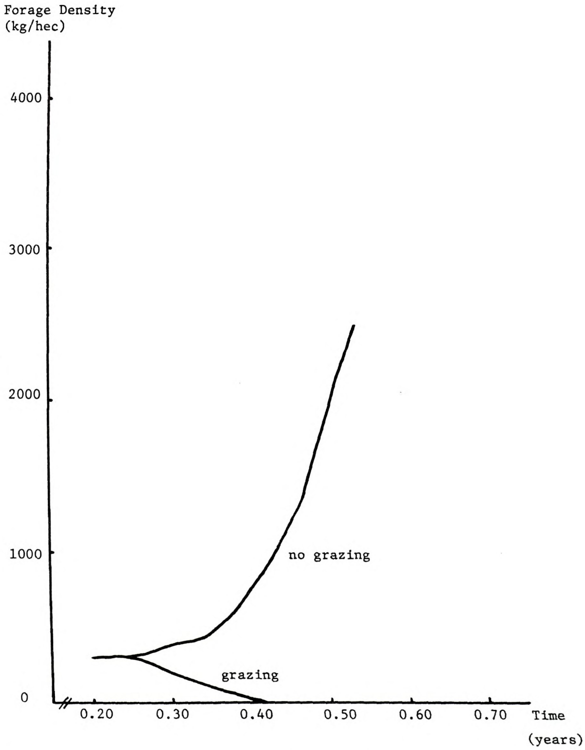

Figure 6.5 Forage densities over time as a result of basic climatic variable inputs and grazing policies

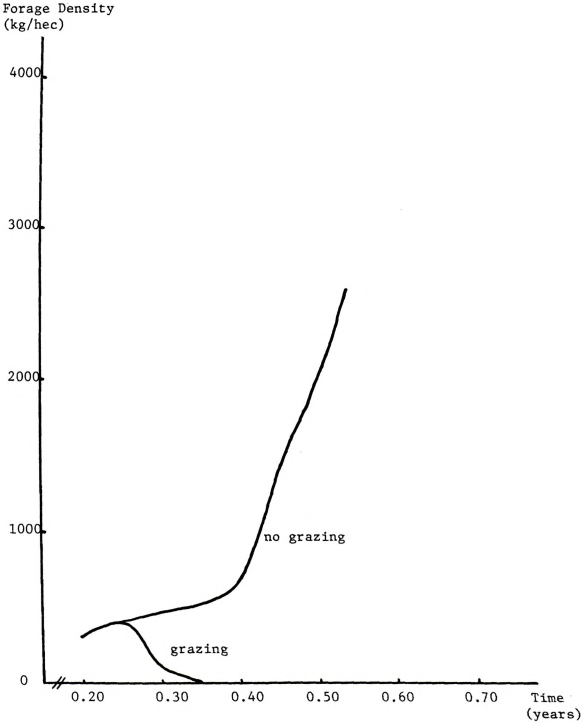

Figure 6.6 Forage densities over time as a result of basic climatic variable inputs and grazing policies

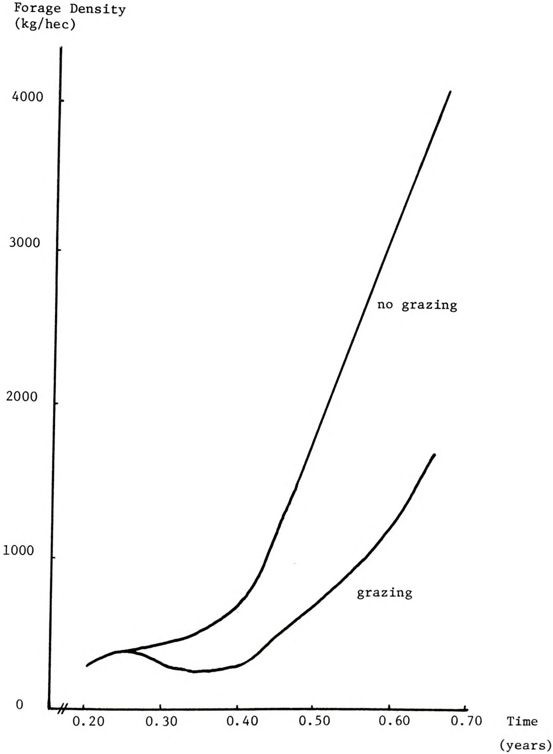

Figure 6.7 Forage densities over time as a result of basic climatic variable inputs and grazing policies

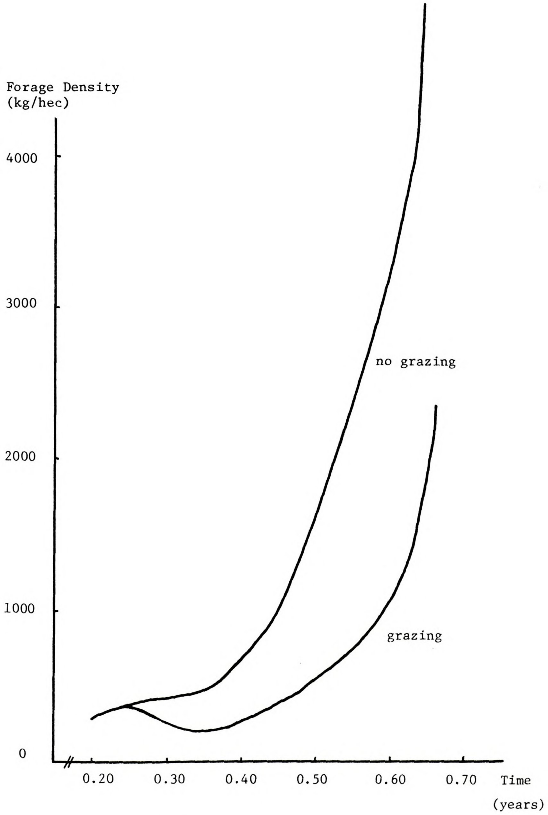

Figure 6.8 Forage densities over time as a result of basic climatic variable inputs and grazing policies

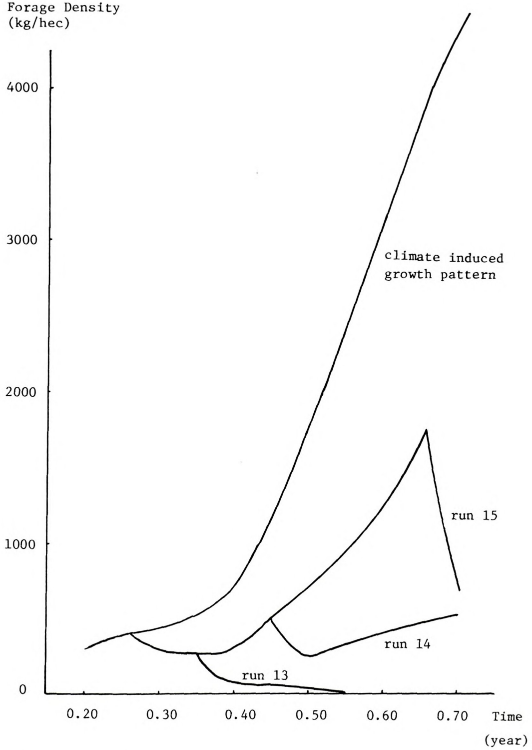

Figure 6.9 Forage densities over time as a result of grazing and harvesting policies

respect to grazing and mechanical harvesting policies. The effects of the policies investigated here are conditional on the weather patterns used in each run. Other weather patterns are, of course, possible; and the results of the specific policies could change with such different weather patterns. Finally, more exhaustive policy tests would be certain to reveal superior policies yet.

Prediction

Section one of this chapter indicated that prediction is the final step in model validation. Prediction is not attempted until the model has passed through the preceding three steps in the validation process. Once the model is thought to be ready for use, it is used, but on a tentative basis. The model will make time predictions that can be verified simply by waiting for real events to catch up to simulated events. An extremely helpful action at this point would be careful data collection oriented to the variables used in this model and predicted by it. This allows tracking procedures to be used to identify time series which are not as well modeled as others and, thereby, indicate areas where parameter changes or new model structure is needed. This final stage of validation is also a time when users can begin to develop confidence in the model as they see it work and improve over time. Gradually the model will be more and more reliable, and the validation effort can be concluded.

VI.3 Summary

This chapter has presented a hierarchy of validation steps which a model must pass through before it can be considered verified or

validated. These steps are logical consistency, tracking historical data, satisfaction of expert "eyeballing", and prediction. A large number of examples of logical consistency have been presented here for the beef cattle enterprise model, as well as some discussion of satisfaction of expert "eyeballing." Tracking of historical data has not been attempted simply for lack of suitable test cases. Prediction must wait for an actual model user willing to devote the necessary resources to this final step in the validation process. In short, the model in its current state is well down the road of validation, but it has not yet completed the validation stage of model development.

Chapter VII

MANAGEMENT STRATEGIES

This chapter will be the primary report of uses of the simulation model to investigate management strategies of decision-making. Three topics will be covered here: an orientation to management strategies as used in the model, several illustrative demonstrations of the model and its capability, and a summary of what has been learned from these sample demonstrations.

VII.1 Strategies of Management Decision Making

Although this model contains many quite detailed control variables to allow realistic simulation of an actual enterprise, its main usefulness lies in investigations of broader questions of management decision-making. As used here the word strategy refers to an approach to management or operation which embodies a multiple of individual decisions. An example of a management strategy is the question of whether to sell calves as they are weaned, or to retain them for sale later as yearlings. A relatively fundamental difference exists between these two modes of operation. Quite different cash flow patterns would be expected, as well as rather different wintering feed requirements, etc. Detailed decisions to be made within each of these strategies include how much and what type of feed to allocate to the herd cohorts, how to effectively use forage growth, and what sales date should be followed. The simulation model accomodates these types of decisions through the mechanism of decision points where the user has the choice of alternative actions to take to control the behavior of the enterprise. These

decision points occur as often as complex decision requiring the input of a decision-maker are encountered.

VII.2 Demonstration Examples of Strategy Investigations

This section will discuss specific uses of the simulation model in investigating alternative strategies of management decision-making. Three different and distinct areas of management strategy will be evaluated here:

(1) early versus late weaning of calves

(2) the rate of development appropriate in increasing the steady state size of the breeding cow herd

(3) general profit maximization for a given breeding cow herd size.

These three examples have been chosen as the means of illustrating the capability of the simulation model because of the wide range of decision-making that they encompass. The reader can think of numerous other examples which might be just as appropriate as these. In order to cover these three examples in the limited time and space available, the testing will be under typical conditions but will not be exhaustive or complete. The conclusions drawn here should be viewed as tentative and preliminary and subject to further testing before being confirmed.

The major criterion for comparing the strategies tested here will be financial; this is in keeping with the subject being discussed in this thesis--a profit maximizing agricultural business. Other criteria will be used when appropriate to reflect differences not handled or poorly handled by financial considerations.

The three demonstration examples to be discussed in the remainder of this chapter require numerous exogenous variable specifications

through time. These variables fall into four groups: expected prices, climatic variables, crop production, and miscellaneous. Expected prices over time are required for the five cattle price grades, the eight production resources, and for each of the feed stocks. Climatic variables required are the solar radiation, average daily temperature, and rainfall patterns through time. Crop production specifications include the timing and quantity harvested for each feed stock. The miscellaneous category includes the quantity of grazing land and its divisions into homogeneous parcels, the property tax rates, as well as other initial conditions.

All three demonstrations will use an expected price pattern which assumes an annual cycle of price fluctuations for cattle and feed stocks. Expected prices for the eight production resources are assumed to be constant through time. Figures 7.1 and 7.2 illustrate the pattern and degree of fluctuation for expected prices of cattle of grade 1 and feed stock 1 (forage), respectively. A pattern of constant prices will be used in the weaning timing demonstration for comparison with the cyclic prices usually assumed. Such prices will be roughly midway between the highs and lows of the cyclic price pattern. Figure 7.3 illustrates the annual pattern of solar radiation incident to the enterprise site. Forage harvesting will be performed at the end of the growth season as well as within the growth season at $T = 0.55$. Finally, the onset of spring growth and the end of the growing season are assumed to be 0.25 and 0.80, respectively, throughout all runs for these three examples. The many other initial conditions required to operate the model will not be specifically mentioned; unless otherwise noted such initial conditions are uniformly applicable over all the model runs discussed.

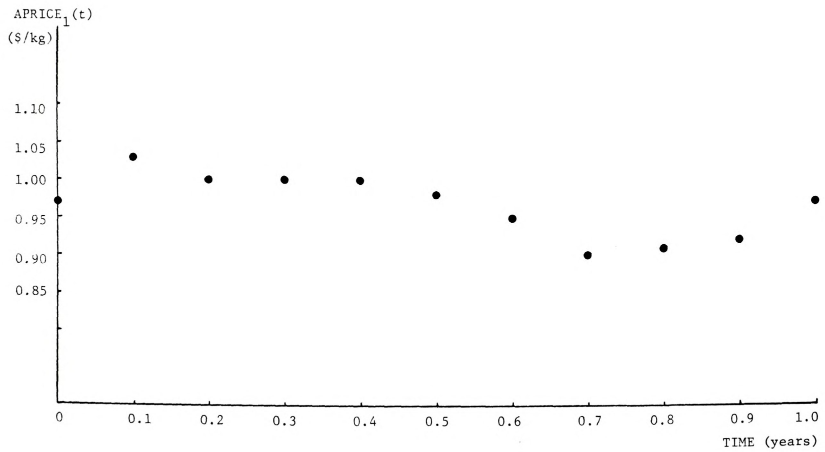

Figure 7.1 Annual pattern of cyclic cattle prices used in demonstration runs

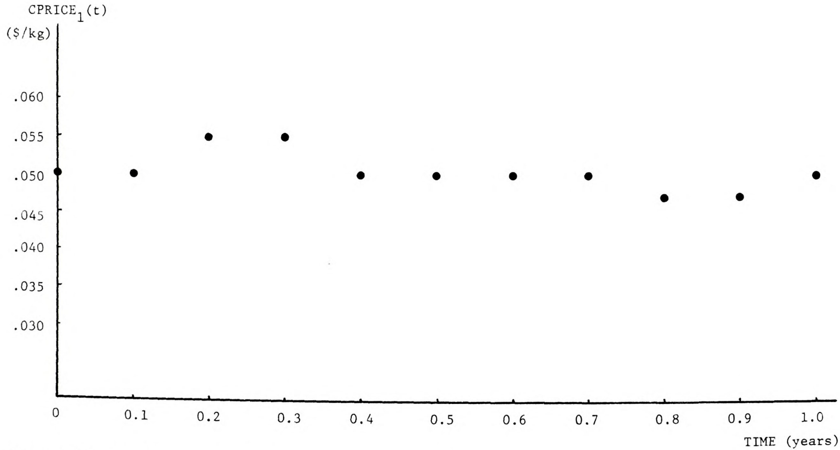

Figure 7.2 Annual pattern of cyclic crop prices used in demonstration runs

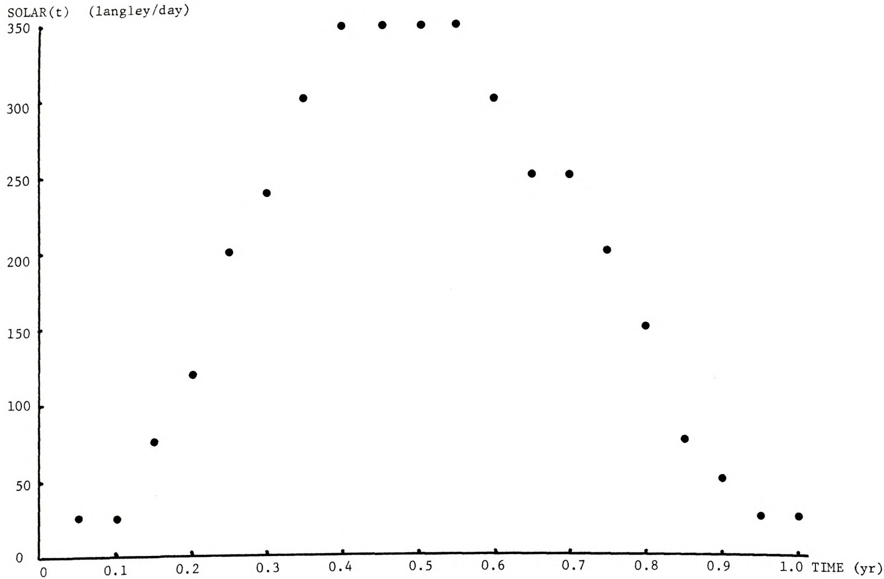

Figure 7.3 Annual pattern of solar radiation incident on the enterprise site

Early Versus Late Calf Weaning

The first illustrative example of the beef cattle enterprise model will concern a relatively self contained policy issue--should calves be weaned early or late? Beef producers face this decision on an annual basis, so it is a question of concern. The effects of these policy alternatives are largely confined to three areas, although secondary effects are numerous. These three areas are (1) overall profit effects resulting from sales of either light or heavy calves to the market, (2) total feed requirements with retention of calves into the winter feeding season, and (3) effects on estrous cycling in calves selected as replacements for the breeding herd.

The exogenous variables used in the runs to examine this policy issue were largely as described earlier in this section. However, the cyclic prices used most frequently throughout the runs discussed in this chapter were augmented by a pattern of constant prices for purposes of comparison. Feed stock production was assumed to be 45000 kg of shelled corn at T = 0.65, 20000 kg of corn silage at T = 0.70, and 15000 kg of rye grass at T = 0.75. 660 hectares of grazing land was divided into five parcels of 200, 200, 100, 100, and 60 hectares. Property taxes were assumed to be $50 per hectare per year.

Four runs of the model were made to investigate the major effects listed above. The time horizon covered by these runs was from T = 0.0 through T = 1.25. An experiment involving two factors was performed, with the first factor being age of weaning, and the second factor being the annual pattern of prices expected. Age of weaning was tested in two groupings, with the age of weaning ranging from 3 to 5 months in the early weaning group, and from 5 to 7 months in the late weaning group.

Price patterns were also tested in two groups; the first group used constant cattle, production resource, and feed stock expected prices, while the second pattern had cattle prices cycling on an annual basis as exemplified by Figure 7.1. Peak cattle prices in this second pattern were in the spring with minimum prices in the fall corresponding to the traditional weaning/culling time.

Table 7.1 reports the results of the four simulation runs which evaluate the effect of weaning age on enterprise behavior. Early weaning--constant prices, early weaning--cyclic prices, late weaning--constant prices, and late weaning--cyclic prices are the four runs reported in this table. Five factors of primary importance are listed for each run; these are annual cash flow, revenue earned from calf sales, total purchased feed stocks consumed, replacement heifer estrous onset, and bred heifer estrous onset. The first three of these factors are obtained from the end of the year financial summary, while the last two are obtained from the intermediate print statements at time T = 1.25. This latter time happened to be the time at which the simulation model determined the age of heifer estrous onset.

In Table 7.1 the run with the minimum cash outflow (all four have negative cash inflows for the year) is run 3, i.e. late weaning with constant prices. This is largely due to the fact that it is also the run with the largest revenue earned from calf sales. Even with cyclic prices, however, late weaning is financially superior to early weaning as is demonstrated by run 4. The higher calf weights at a later time of weaning are responsible for this superior financial performance.

Late weaning also resulted in a slightly smaller total feed consumption (of purchased feed stocks) than early weaning. This was due

Table 7.1 Results of Sample Runs Investigating the Effects of Early Versus Late Weaning of Calves

Run	Description	Annual Cash Flow ($)	Weaned Calf Sales Revenue ($)	Total Feed Consumption (kg)	Onset of Heifer Puberty Cohort 2 (yr)	Onset of Heifer Puberty Cohort 3 (yr)
1	early weaning constant prices	-31320	13720	796900	1.2166	1.2870
2	early weaning cyclic prices	-32670	13720	796900	1.2166	1.2870
3	late weaning constant prices	-28830	15890	790000	1.1807	1.2555
4	late weaning cyclic prices	-30500	14500	790000	1.1807	1.2555

to the fact that calf nutrients could be partially supplied by grazing during the early fall period, but were mainly supplied by lactating cows which themselves were grazing and therefore not consuming feeds which are counted in the quantity listed in Table 7.1.

Additionally, the ages of the heifers at first estrous, both for replacement heifers and bred heifers, were younger for late weaned calves than for the early weaned calves. In both late and early weaning the oldest group of female calves were selected for replacements, and the second oldest were selected for bred heifers. All of the other calves were sold on the market. The age difference between the oldest and second oldest female calf groups selected accounts for the difference in the ages of first estrous between replacement and bred heifers. The age difference , for both replacements and bred heifers, between those weaned early and those weaned late is only 0.0359 years, or approximately two weeks. This difference would have some effect on the rate of pregnancy achieved for the two heifer groups during their first breeding, but only in a marginal way.

The overall conclusion drawn from this set of four runs of the model is that late weaning is to be preferred to early weaning even under adverse price expectations. Only when the expected fall in prices for cattle during the fall period is so severe so as to more than offset the increase revenue from heavier animals should early weaning be considered. Even in this instance the consequences of additional purchased feed consumption and delayed estrous onset should be carefully considered before early weaning is adopted.

Rate of Development

This example of the capability of the enterprise model illustrates the ability of the model to assist in project investment planning. The three cases considered here are ones which would be considered among the range of possible approaches to achievement of the goal. The project to be investigated here is achievement of a steady-state breeding cow herd of 200 animals within three years of project initiation. The three cases tested are (1) purchase of 200 bred heifers and no other animals, (2) purchase of 250 mature cows and no other animals, and (3) purchase of an entire ongoing herd having a steady-state cow population of 100 animals. Certainly other possible initial states exist, but these three will be the ones tested in this model demonstration.

Each of the three runs discussed here shares the same common exogenous variable environment. The standard weather pattern used in the majority of the simulation runs of this thesis is again present here. Figure 7.3 illustrates the solar radiation pattern of this weather set over the calendar year. Annual cycle of cattle and crop prices is expected with peak crop prices in the spring and minimum prices in the fall. Similar timings of the cattle price fluctuations are assumed. Figures 7.1 and 7.2 illustrate typical levels of price fluctuation and the timing of these fluctuations. Production resource prices are assumed constant throughout the three-year time interval evaluated. All runs begin at T = 0.0 (corresponding to January 1 of the calendar year), and spring calving was used for all three runs. The grazing land parcels were identical to those of the weaning demonstration, as were the feed stock production quantities and timings.

Property taxes were again \$50 per hectare per year and due in semi-annual installments.

Figure 7.4 indicates the convergence of the mature cow populations of each of the three cases toward the target value. Case 1 population increases rapidly from zero to 200 because the initial conditions were 200 bred heifers which quickly had their calves and became mature cows. Subsequently this population drops below 200 because there are no replacement animals to take the place of cows which die or are culled. Only as replacements are generated from the first calf crop does the population again approach the desired level of 200. Case 2 exhibits a steady drop from the initial level of 250 cows that one would expect because culls and deaths are not replaced with incoming heifers until the first calf crop matures to replacement heifer age. Case 3 follows a slow but steady path of population increase that is expected of a herd which began at a level of 100 and which is growing solely through retention of weaned female calves. Culling is at a very low rate in this case to maximize cow population. All female calves are retained for replacement heifers to minimize the time required to reach the target population. By T = 3.0 Cases 1 and 2 are quite near the desired population target, but Case 3 is still somewhat short of this goal. Had the plot of Figure 7.4 been extended to T = 3.25, then all three cases would have been slightly in excess of the target population. The considerable rise in the Case 3 population would have been due to the large number of replacement heifers (retained from previous calf crops) which would be changing cohort designations as they become two years old. All three cases can be considered to have reached the target.

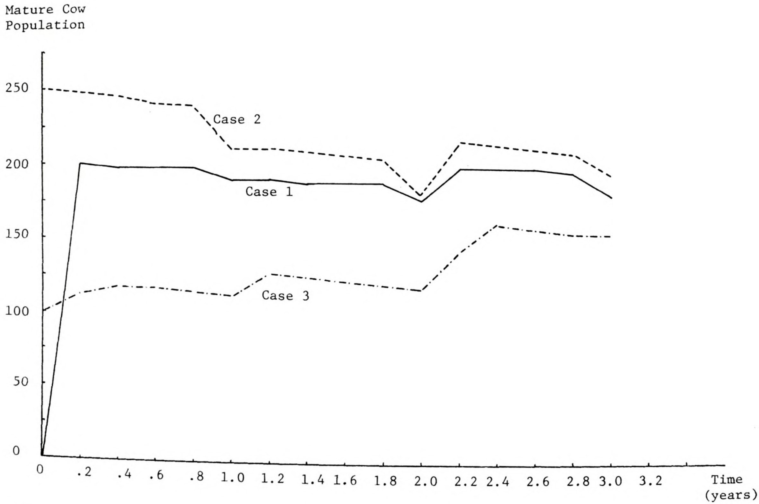

Figure 7.4 Mature cow cohort populations through time for three investment patterns

Selection of a "best" rate of development from among a group of alternatives is most likely to be made on the basis of financial return. The selection of criteria to determine this return is a decision which should be made quite carefully. Operating characteristics as well as some measure of the change in value of property and assets should be made. For this demonstration example the cash flow of the runs and the change in net worth of assets other than land will be the criteria used for selecting the best alternative. Cash flow will be discussed in terms of overall accumulated flow, annual cash flow, and per period cash flow. Net worth will be discussed in terms of long and short term debt, change in value of feed stocks on hand, and change in value of the cattle herd. Operating capital levels will also be included.

Figure 7.5 illustrates the cash flows on an annual basis for the three cases under consideration. All of them share the characteristic of being highly negative; this indicates the current poor condition of the cattle industry faithfully. High feed prices and low cattle prices are the cause of this situation. Case 1 is less negative than the other two alternatives in years 2 and 3, but case 3 actually made money in the first year. Case 3 then plunges down to the worst position of the three for years 2 and 3. This drop can be attributed to low revenues associated with retention of all female animals to maximize calf births in the following years. A reason for the highly negative cash flows of the three alternatives is the debt repayment made necessary by borrowing to meet the needs of the enterprise during the long intervals with negative cash flow. Typical loan conditions used here was repayment within one year at 10% interest on the unpaid balance. These terms

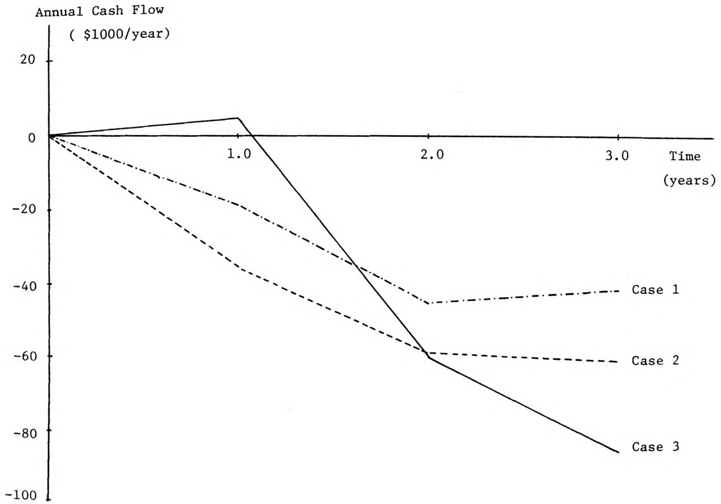

Figure 7.5 Annual cash flow patterns through time for three investment cases

insure that the loans must be rolled over since the entire three year interval produces no windfall of revenues to enable the enterprise to eliminate them entirely. If more favorable terms could be arranged then the cash flows would not be quite so bad, but then the debt situation would not be as good.

More detail on the timing of cash inflows and outflows contributing to the annual patterns of Figure 7.5 are given by Figure 7.6. Here the individual DT time increments of cash inflow have been aggregated into values for intervals of 0.20 year. Cases 1 and 2 show quite similar patterns of cash flow over the entire three year project duration. Case 3 differs somewhat from the other two, but becomes more similar as time approaches the end of the project. The working capital requirements of the enterprise can be determined through integration of the consecutive periods of cash outflow. Such outflows must be covered by working capital on hand at the beginning of the outflow interval, or by borrowing during the outflow interval with repayment to be negotiated between the borrower and the lender.

The change in net worth of the enterprise is a function of the change in herd composition and age structure, changes in the feed stock inventory, changes in the level of working capital, and debt load. Table 7.2 illustrates the net worth changes which have occurred over the three year time horizon of these investigations. The initial cattle herd valuations are strictly a function of the composition of the herd at $T = 0.0$, as initial feed stock valuations are solely determined from the quantities of each feed stock on hand. All three cases shared a

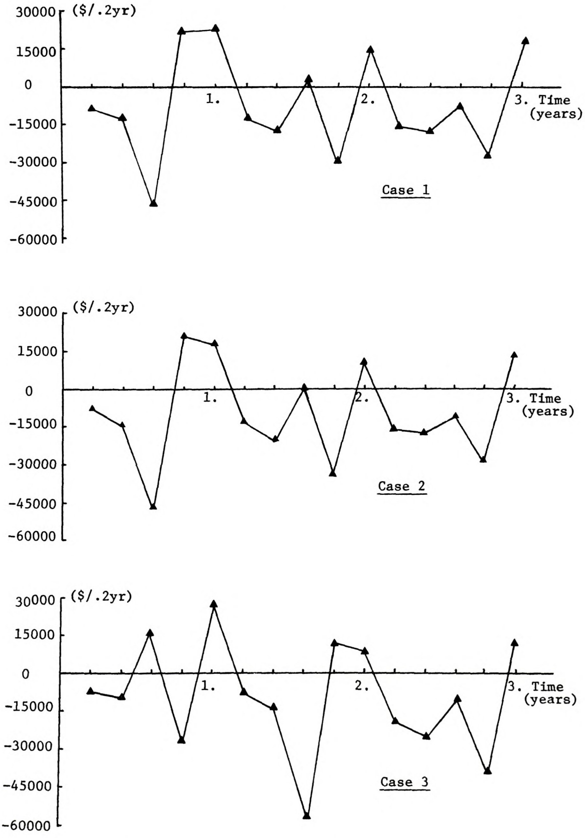

Figure 7.6 Pattern of cash flows through time over the 3 year time horizon of the investigations for Cases 1, 2, and 3

Table 7.2 Change In Net Worth Over Time

Financial Variable	Case 1	Case 2	Case 3
Initial--T = 0.0			
Value of cattle	32000	92500	64900
Value of feed stocks	21060	21060	21060
Working capital	45000	45000	45000
Long term debt	62100	122600	95000
Short term debt	0	0	0
Net Worth of liquid assets	35960	35960	35960
Final--T = 3.0			
Value of cattle	80200	83000	83050
Value of feed stocks	20400	18220	25070
Working capital	43370	13330	-7160
Long term debt	0	50600	23000
Short term debt	41200	46400	29000
Net Worth of liquid assets	102770	17550	48960
Change in net worth	+66810	-17510	+13000

common level of net worth of assets and liabilities. The widely varying herd valuations were offset by different debt levels which would represent the borrowing necessary to acquire such herds. Overall net worth at T = 0.0 was set at $35,960, exclusive of land related indebtedness and valuation.

After three years, Cases 1 and 3 have increased net worth while Case 2 has suffered a significant drop in net worth. Cattle and feed stocks were valued at the appropriate prices in effect at T = 3.0 to obtain these end of project figures. Due to the annual cattle and crop price patterns used throughout this dissertation, the prices in effect at T = 3.0 happen to be identical to those in effect at T = 0.0. Case 1 had such a large increase in net worth because the herd increased dramatically in value--animals which were initially valued as replacement heifers were valued at the conclusion of the project as mature breeding cows. Overall debt shrank in all three cases, but the rapid repayment of long term debt was offset by large increase in short term debt. The short term debt levels are a result of the negative cash flows which have had to be funded through borrowing.

An overall combination of cash flow and changes in net worth gives a rather gloomy picture for all three development cases. Case 1 has an overall undiscounted present value of -$34,790, while Case 2's value is -$169,210 and Case 3's is -$130,200. Clearly Case 1 is the best of the three tested by a wide margin. Therefore, these tests would conclude that purchase of bred heifers is the best choice from among these three. However, the fact remains that even Case 1 lost nearly

$35,000! Only land speculation or desires for tax losses to offset other taxable income would induce an investor to make this investment under the conditions tested with these runs.

Profit Maximization

The final demonstration of the capability of the simulation model to evaluate and assist in decision making will be a search of selected control values and strategies to maximize profits for a given breeding herd size. Here the breeding cow population will fluctuate around 200 animals with appropriate replacements to maintain this herd size. Three areas of potentially significant financial effects will be investigated: use of artificial insemination versus natural breeding, sales of weaned calves or retention for later sales as yearlings, and herd feeding plans. Monetary considerations of alternatives will be supplemented by other criteria when appropriate in selecting among possible control value sets. Cattle and crop prices will be assumed to fluctuate on an annual cycle as illustrated by Figures 7.1 and 7.2. The weather variables will be assumed to follow the pattern given by Figure 7.3--a plot of solar radiation levels over the calendar year. Property taxes are assumed to be $20 per hectare per year, and due in equal installments June 30 and December 31. Total land area allocated to grazing is 660 hectares divided into five land parcels. No land is leased. Small quantities of shelled corn, rye grass, and oat silage are produced for winter consumption.

The decision to select either artificial insemination (AI) or natural breeding over the other has elements of financial cost, breeding

cow conception rates, and genetic change involved. This enterprise simulation model excludes genetic factors completely. Currently, the overall conception rate from AI is the same as natural breeding as long as the onset and duration of breeding are equal. This leaves the direct financial costs as the only viable means of making comparisons between these breeding methods. Two model runs were made to investigate the financial effects of the method of breeding. One had a bull/cow ratio of 1:20 with no AI used, while the other used AI exclusively with zero bull population. Both runs covered the time interval from T = 0.0 through T = 1.0. Table 7.3 summarizes the results obtained.

Use of natural breeding is superior in terms of financial cost by a margin of 4,900 dollars. AI supplies and labor are a large expense which more than exceeds the feed costs and replacement costs of maintaining a bull herd. AI supplies were assumed to be priced at $10 per ampule, which is a typical value. In actual practice there might be the additional factors of different cow and heifer conception rates and genetic changes to modify these findings. However, the financial costs of the two methods of breeding clearly favor natural breeding; enterprise profit maximization implies the use of natural breeding.

Disposition of weaned calves is a question which cattle ranchers face yearly. Should they be sold after weaning, or retained for sale later as yearlings? Immediate sale had the advantage of lower winter feed requirements, less labor in general animal care and feeding, and a known current market price. Retention for later sale speculates that the increased revenue of selling heavier animals will offset the

Table 7.3 Breeding Method Cost Comparison

Factor	Costs of AI Breeding ($)	Costs of Natural Breeding ($)
Labor and AI supplies	10,980	---
Bull feed costs	---	1,270
Bull replacements	---	4,800
Total	10,980	6,070

costs of keeping these slaughter cohort animals. Three separate runs were made to compare the overall financial effects of (1) sale immediately following weaning, (2) retention of female heifers not selected as breeding replacements, and (3) retention of all weaned calves. All animals retained for later sale were sold at T=1.15 when yearly cattle prices were at their peak; animals sold at that time were from 10 to 12 months old.

Table 7.4 indicates the results of these three runs. Total cash flow and net profit are reported for the period (0.0, 1.15). Additionally the values of the feed stock inventories at T=1.20 have been compared and the difference of the two retention runs from the base given. Finally, total cash flow and net profit are adjusted to include the feed stock inventory valuation differences. These adjusted values are a true basis for comparison among the three runs. As the

values of adjusted cash flow make clear, the more weaned animals that are retained the worse off the enterprise becomes. Under the feed plans used, and the basic price cycle specified, the profit maximizing operator would sell all weaned calves not retained for replacement of breeding cows and save none for later sale.

Table 7.4 Financial Effects of Weaned Calf Retention Policies

Factor	Sell All ($)	Sell Males ($)	Sell None ($)
Total Cash Flow	+4770	+2790	+100
Total Net Profit	-5980	-7960	-10650
Feed Inventory Value	0	-3620	-1850
Total Adjusted Cash Flow	+4770	-830	-1750
Total Adjusted Net Profit	-5980	-11580	-12500

The final aspect of profit maximization to be investigated in this thesis is the area of cattle feeding plans. Feeding of cattle is a very significant part of the overall cost of a cattle enterprise and offers room for financial savings if feed reductions can be made. The simulation model is well suited to these investigations because of the great flexibility which exists in the quantity and quality of feed that can be allocated to the individual herd cohorts over time. For example, the model user can specify up to four different feeding plans through time and control the time at which allocations shift from one to another. Since these plans are changeable at most decision points the time interval

during which each feeding plan is in effect can be quite short. Within a particular feeding plan the user can specify the quantity of TDN he wishes allocated to each cohort's animals for both concentrates and roughages per day. The units of the control variables of the feeding plan are kg TDN/animal/day. Further, the user can specify what fraction of the roughage and the concentrate allocation is to be obtained from what feed stock. This model organization gives the model user nearly as much flexibility as an actual enterprise manager in feeding cattle.

A series of eight simulation runs of one year's duration was made, attempting to reduce feed allocations without hurting cattle performance. The base run had a series of six feeding plans covering the entire one-year interval drawn from rough adherence to recommended guidelines. Two different sources caused misallocations where improvement was obviously attainable. First, several instances occurred in which the allocation to animals of a particular cohort was more than they would consume. This excess is considered totally wasted in the model (see section V.4 for details). Second, several other instances occurred in which the allocation to animals of a cohort gave a projected daily weight gain rate which conflicted with the weight maximum constraining that cohort. In such instances any daily gains exceeding the weight maximum are disallowed (see section V.1 for details). Thus, the immediate goal was to eliminate these sources of excess feed consumption from the feeding plans.

Table 7.5 indicates the results of the eight model runs over the time interval (0.00,1.25). Run 1 is the base from which improvements

Table 7.5 Financial Effects of Alternative Feeding Plans

Description	Run 1(base)	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
1. Feed Allocated								
forages	162860	165890	164340	162970	162970	113640	113640	113650
shelled corn	73760	67190	68460	73310	68470	58650	68810	48510
soybean meal	75140	68410	69710	74680	69730	59640	70060	49250
rye grass	29530	43550	43280	53900	53900	40130	40130	40120
oat silage	20390	20800	20600	20420	20420	14350	14350	14350
corn silage	44260	45120	44700	44320	44320	31220	31220	31220
2. Feed Inventory(T=1.0)								
forages	121370	131550	154030	165820	159810	181140	185180	174740
shelled corn	41740	41280	40020	40100	44860	54600	64060	46970
soybean meal	44590	41300	40020	40030	44970	40050	49560	32480
rye grass	18690	29660	29920	24820	19840	33480	33520	33440
oat silage	15620	20160	20340	20500	20500	26470	26560	26370
corn silage	33070	33300	33710	34080	34080	37110	37110	37110
3. Inventory Value	21600	22040	22860	23340	24220	26530	29340	24130
4. Annual Cash Flow	10890	11180	10910	9530	9350	12350	6010	17460
5. 3. difference over base	-	+440	+1260	+1740	+2620	+4930	+7740	+2530
6. 4. + 5.	10890	11620	12170	11270	11970	17280	13750	19990
7. % Improvement over base	-	+6.7	+11.7	+3.5	+9.8	+58.6	+26.2	+83.5

were to be made. Run 2 increased the mature cow allocations during calving to attempt more rapid weight recovery, while also decreasing allocations to replacement heifers and mature bulls. Both these latter two cohorts were being allocated excessive feed quantities; heifers were allocated more than they would consume, while bulls were fed so much that the resulting daily gains took them beyond the weight constraint of 600 kg. A small improvement in the overall financial measure of Run 2 was shown--approximately 6.7% better than the base run in terms of the combination of annual cash flow and the excess feed inventory on hand.

Run 3 attempted to the correct the problems still remaining after Run 2 by further decreasing replacement heifer feed allocations in the early part of the year, and by reducing the allocations of concentrate to bulls throughout the year. These changes resulted in another small increase on overall profitability as total feed allocated was reduced. An 11.7% improvement from the base run was achieved.

Runs 4 and 5 departed significantly from the feeding plans of the first three runs. Early year cow and heifer pre-calving feed rates were increased to reflect the common practice of boosting energy intake prior to calving. Run 4 also added a schedule of feeding calves supplementary concentrates during the later summer months. These increased concentrate allocations are reflected in the higher concentrates consumed values in Table 7.5. The overall financial result was still slightly better than the base run, by 3.5%, but a drop from the previous runs. Run 5 eliminated the summer concentrate supplements to calves of Run 4, but was otherwise identical to it. Its overall financial result was

a gain from the results of Run 4, but still worse than Run 3. A 9.8% improvement over the base run was obtained.

Run 6 made another significant change by extending the grazing season, where no supplementary feeding is made, from T = 0.70 through T = 0.80. This latter time value is the beginning of the wintering season as defined with the use of the variable TFALL. This increase in grazing period is significant because of the large number of cattle which are present in comparison to the rest of the year. Calves are able to eat quite a lot with full weaning being only a short period into the future (TWEAN = 0.85). Elimination of this period of feeding saved expensive feed stocks by substituting forage which is relatively low in cost. The overall financial effects were startlingly good-- a 58.6% improvement over the base run.

Runs 7 and 8 use Run 6 as a base and differ from it by increasing or decreasing post-calving cow concentrate supplementation, respectively. Observation of the overall concentrate consumptions listed in Table 7.5 shows roughly 10,000 kg increases in Run 7, and 10,000 kg decreases in Run 8, from the base levels of Run 6. Overall financial effects reflect these levels of change in concentrate consumption, with Run 7 dropping to only 26.2% better than the base run, and Run 8 increasing to 83.5% better than the base run.

The above discussion of the effects of alternative feeding plans has concentrated on the financial effects without mention of some more subtle feeding effects. One of these effects is the condition of the breeding cow herd as related to calving, lactation, and rebreeding. Table 7.6 gives an idea of the feeding plan effects on cow condition

by presenting ranges of weights of cohort 1 cows (at T = 1.0) for each of the eight runs. Three basic groupings may be made from the eight runs: (1) Runs 1 and 8, (2) Runs 2, 3, 4, 5, and 6, and (3) Run 7. Runs 1 and 8 presumably have comparable levels of breeding cow condition as the weight ranges are very similar. Run 8 is vastly better than Run 1 financially, so it would be preferred to Run 1. Runs 2 through 6 have very similar weight ranges implying a uniform cow condition among them, while Run 6 has much better financial outcomes than the others. Run 6 should then be preferred over the others. Finally, Run 7 has a somewhat better condition than either of the other two groups.

Choice of the best overall run of these eight is difficult because of the inverse relationship between the two measures of outcomes. Figure 7.7 plots these conflicting results. Decisions about what is preferable among these groups of runs--numbers 6, 7, and 8-- must be made on the basis of the weights assigned to the two measures of performance. If the weight differences are relatively unimportant, then Run 8 is best. If the weight differences are very important, then Run 7 is best. Perhaps Run 6 is best under moderate importance of both measures. The decision maker must decide for himself.

Profit maximization (or loss minimization) is an open ended proposition. This demonstration of the capability of the model has touched on three areas which seem likely to be important to achievement of the goal. Of course, many additional aspects have not been examined at all. The results of these model runs do tentatively support the proposition that profit maximization implies natural breeding not AI, sales of weaned

calves immediately not retention, and a tight level of feeding. Run 6 is probably characteristic of such feeding levels. Other conclusions could possibly be drawn here if the assumptions about price, weather, and crop production change significantly. Additionally, a more sophisticated model which includes an improved model of the energy intake/reproductive potential interactions might obtain somewhat different and more conclusive results with regard to the effects of the feeding plan alternatives discussed here.

Table 7.6 Mature Breeding Cow Conditioning Effects From Alternative Feeding Plans

Run	Weights at T = 1.0		
	Average (kg)	Minimum (kg)	Maximum (kg)
1	386	358	419
2	405	372	440
3	406	371	440
4	406	370	440
5	406	370	440
6	396	367	440
7	417	380	443
8	385	351	423

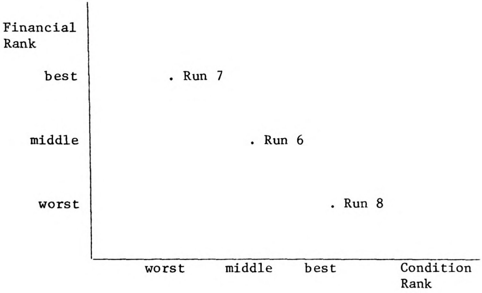

Figure 7.7 Plot of the rankings of runs 6,7, and 8 according to financial ranking and condition ranking

VII.3 Summary

Three demonstration examples have been presented to illustrate the capability of the simulation model to assist decision makers in ongoing operational decisions and in investment planning. The question of early versus late weaning was decided in favor of late weaning. Of the three paths tested for achieving a steady-state breeding cow herd of 200 animals, the best method was to begin with 200 bred heifers and generate herd replacements internally. Profit maximization turned out to imply natural breeding as opposed to artificial insemination, sales of all weaned calves immediately following weaning rather than retention for later sales, and a tight level of herd feeding. All of the conclusions determined through these demonstrations are tentative, because the purpose of these investigations was merely to illustrate the capability of the model, not to come to a definitive conclusion about a particular decision rule of management. Confirmation of these findings could be achieved through more extensive testing with the simulation model in conjunction with improved data.

The deterministic nature of this model and its output variables could be modified to allow running in a Monte Carlo mode of operation. This would provide confidence intervals on the output variables as related to randomness in the various variables of this system. For example, the weather variables used in the runs at present are deterministic not random as they are in nature. Forage growth should, therefore, be a stochastic variable responsive to the random variable values of solar radiation, average temperature, and rainfall. The financial variables of the model would then be stochastic in response to different levels of forage growth for any given management policy.

Confidence intervals could be determined around the financial outcomes indicating the degree of fluctuation of them from weather variation. Managers might prefer policies which while less attractive on the average have less variation around the mean. The preferences of the manager toward uncertainty could then enter into his decisions regarding investment and management policy.

These three demonstration examples do confirm the usefulness of the simulation model in assisting management decision makers. Both ongoing operating decisions and project investments of a realistic nature can be evaluated with the model in its current form. A tool such as this model should allow decision makers to perform better since a much wider range of alternatives is open to analysis and objective comparison. Information is generated which the manager can use to significantly reduce the risk and uncertainty which are associated with particular management strategies. While the development of this model is costly, the operating expenses of using it are extremely small in comparison to the potential advantages that can be gained from better responses to economic forces and the environment. Many questions of significance could be answered in a day of programmer time and $50 worth of computer time, as measured on the MSU CDC 6500. The great flexibility of the model should make it of interest to many different users.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

This thesis will end with a summary of the preceding seven chapters, the conclusions to be drawn from the development and use of the model, further extensions and improvements to the model, and implementation of the model.

VIII.1 Summary

The preceding chapters have discussed in great detail the development and use of a system simulation model of a beef cattle enterprise for the purpose of investigating alternative management decision making strategies. Chapter IV developed the general description of the modeling approach that has been taken, while Chapter V discussed the details of the mathematical model as implemented in the FORTRAN subroutines listed in the User's Guide to the Beef Cattle Enterprise Simulation Model, a separate volume from this thesis. The details of the growth prediction and reproductive impact component can be found in Schuette [48]. This simulation model represents a strong attempt to fully model the time dynamics and reproductive dynamics of a beef cattle herd; this is an area which has been neglected up to this time. Furthermore, the intent of this thesis has been development of a practical tool for decision makers which can be helpful in providing evaluations of alternative decisions.

A general model of a beef cattle enterprise which leans toward the land-extensive cow/calf form of operation has been viewed as containing five major system components. These are

1. cattle herd demographics--a description of the herd at each point in time by age, sex, function, and, weight;

2. forage growth component--dynamic plant growth of forage as influenced by climatic variables and mechanical and animal harvesting of plant material;

3. feed stock component--accounting for the quantity and quality of cattle feed stocks through time;

4. nutrient impact component--determination of the response of cattle to feed intake rates in terms of growth and of reproductive potential;

5. management decision-making component--the decisions and actions needed to manage the herd on both long- and short-term bases.

Additionally there are several secondary components which determine the financial effect of actions, generate proper values of exogenous variables through time, etc. Figure 4.12 is repeated here to summarize the components of this system and the interconnecting variables.

A key feature of the management decision making component is the distinction between decisions which the model itself can determine endogenously and those which must await exogenous control by the model user. Currently there are seven instances in which the model must stop and be restarted with appropriate control variable values determined by the user after study of the preceding simulation results and the current states of the system. These seven events are organized into five "decision points" which correspond, in part, to natural cattle phenomena. These decision points occur when:

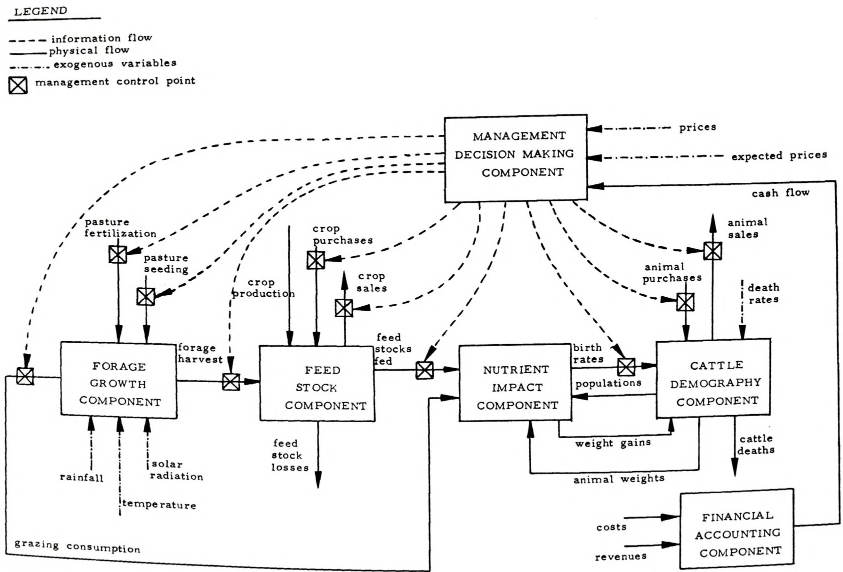

Figure 4.12 Enterprise system diagram illustrating physical and information flows between components

(1) spring plant growth begins

(2) herd breeding begins

(3) calf weaning occurs

(4) mature cow culling occurs

(5) working capital falls below $2,000

(6) feed stock levels fall below the requirements for the next two successive simulation time increments

(7) final harvest feed stock levels are more than a specified per cent out of balance with winter feed requirements.

Further and extensive use of the model may reveal decision rules which can be incorporated into the management decision making component and reduce the number of events which require exogenous control by the model user.

A primary reason for requiring exogenous user decisions is the long time delays characterizing this system and the highly volatile prices in cattle markets during recent years. Control variable values optimized with reference to some suitable objective function are conditional on the price and other variable expectations that were used; these values may be far from optimal under different exogenous variable conditions. In response to this situation the management decision making component has been designed to require exogenous user decisions at points where long time delays make automatic decision rule actions infeasible. Thus the above list of events has been determined to require exogenous control.

The present simulation model, as it is described in Chapter V and the User's Guide...., fulfills the problem statement requirements as given in III.4. This is not to say that improvements and extensions

cannot be made--certainly they can, a later section of this chapter will review such areas in some detail. The model is fully capable of examining many questions of long-range management decision making, as is evidenced by the illustrative sample runs of Chapter VII.

VIII.2 Conclusions

This thesis has developed a batch interactive simulation model of a beef cattle enterprise system. With the exception of land allocation and crop production aspects, the entire system has been modeled as FORTRAN programs and subroutines. The entire model requires 130000 octal words of core as run on the MSU CDC 6500. This is a very large memory requirement, but it could be reduced through more sophisticated programming. Running costs of the model are quite low, with the cost of a single year of simulated time requiring approximately $7.50. A budget of $50 for computer time, and a day's salary for a programmer familiar with the model's operation, could obtain very significant information for use by management decision makers.

The model is designed to be, and is capable of, investigating the effects of management decisions on the physical and financial variables commonly of interest to actual decision makers. The goal throughout this thesis project has been to develop a practical tool to allow decision makers increased ability to evaluate the consequences of their decisions on the enterprise. This goal has been accomplished. Improvements and extensions remain, but the present form of the model is capable of profitable use in operational decisions and investment planning.

An accomplishment of this thesis has been construction of a realistic model of the dynamics of herd growth and reproductive dynamics

across the entire range of cattle types and uses. A second accomplishment has been the development of an interactive management decision making component which makes decisions endogenously, if possible, and asks the user for exogenous decisions where needed. A third accomplishment has been the development of a forage growth component which uses exogenous weather variables and forage removal (by machines and by animals) to obtain forage dynamics. This model is data oriented and can be used independently of the main simulation model. A fourth accomplishment has been development of a discrete time delay subroutine which is capable of having a dynamic delay time and proportional losses from the intermediate storage values.

Since this thesis has not been used in a practical setting to date, its major accomplishment has been to contribute to the integration of separate stocks of knowledge and understanding of the beef cattle enterprise operation. This has involved areas of agricultural economics, animal husbandry, cattle physiology, crop sciences, and management decision making. The system science methodology for modeling and simulation of general systems has been the integrating factor which has been responsible for development of this model.

The three demonstration examples of Chapter VII have been tentative investigations that are intended to illustrate the capability of the model to evaluate a wide range of questions of interest to management. The conclusions reached in that chapter should be considered preliminary and are, of course, conditional on the prices and other exogenous variables used. Briefly summaried, the following conclusions were made:

(1) Late weaning of calves is preferred to early weaning.

(2) Investments designed to obtain a steady-state cow herd of a specified size within a stated three-year period should begin with bred heifers.

(3) Profit maximization implies no retention of weaned calves for later sales. Natural breeding should be employed instead of artificial insemination. And a tight feeding schedule should be adopted.

These conclusions could be confirmed by further evaluation using the simulation model to test other conditions and exogenous variable values, if no better strategies were to be discovered.

VIII.3 Improvements and Extensions to the Model

Few modeling efforts reach an end point from which improvement and extension are not possible. This model is no exception; there are a number of areas of improvement and extension that will be discussed in this section.

A fundamental factor in this simulation model has been representation of the cattle population dynamics using a mix of discrete and distributed time delay models. There is some error in this approximation due to the nature of the FORTRAN subroutines which are used to represent these time delays. The distributed delays work quite well with large population numbers; but as the population drops, the error becomes larger and larger in significance. For example, in the bull cohort, populations in the delay model are usually in the neighborhood of ten animals with a cow herd of 200 animals. With this few animals, the delay model functions rather poorly; after a three-year simulation run, the number of bulls is down to five or six indicating that the distributive effect moving the animals through

the delay is operating too rapidly. An improvement to the simulation model would be development of a delay routine which could handle small populations without excessive error.

Several small changes could be made in the financial component. First, rather than loans being segregated into short and long term, as is presently done, there could be a multiple loan structure, with each loan having its own unique repayment pattern, interest rate, etc. Second, depreciation is currently based on the average total purchase value and an average depreciation lifetime rather than depreciation based on individual items. A breakdown of such physical assets into groups sharing common depreciation lifetimes and times since purchase would be fairly easy to accomplish and would give much more accurate results. Finally, subroutine PRCOST determines the costs of animal and crop production disaggregated to the level listed in Table 5.1. Improvement in the determination of these costs could be achieved through paramater estimation studies for those parameters listed in Table 5.3 or through development of an entirely new structure to determine production costs on the basis of physical resources used during a simulation increment.

Several small changes associated wtih the population demography component could be instituted with relatively small effort. First, the variable $ADDRT_i(t)$ is used currently to add or subtract animals from herd cohorts as a whole. An improvement would be a variable which could add or subtract animals to specific cohort subpopulations. This would be more in line with typical practice of purchasing specific types and ages of animals rather than the mixture of ages that

$ADDRT_i(t)$ in its present form assumes. Second, grade changes as a result of aging and of changing body proportions could be modeled better than is currently done in subroutine WEIGHT. A limitation here, however, is the fact that price grades for cattle are still assigned on the basis of appearance, which cannot be programmed. Finally, death rates for herd cohorts could be made functions of weather values and season quite readily.

Improvements could be made in the method of assigning feed intake levels to the animals within the slaughter cohorts. Presently, these cohorts use the same feeding plan structure as the remaining herd cohorts; that is, the level of TDN from concentrates and from roughages and the distribution of these among the potential feed stocks is specified by the user. Computation of feeding rate and selling date could be optimized using a number of methods readily available. These optimized values would, however, be conditional on the expected prices for cattle and feed stocks which the user has dictated to the model at the previous decision point. Numerous feed lot optimization models have been constructed in recent years which could either be adapted or incorporated into this model in their entirety to provide the optimization of feeding rate and sales date for the two slaughter cohorts. A major distinction between the two slaughter cohorts and the remaining herd cohorts which allows the slaughter cohorts to have feeding rates optimized is that the reproductive implications of feeding rates do not enter the optimization problem because the slaughter cohorts by their very nature have already been excluded from reproduction.

The harvest of forage by mechanical means is currently performed on all land parcels regardless of whether animals are grazing there or whether particular conditions merit special consideration. An improvement to the forage growth component which would remove this difficulty is having specified harvest fractions for each land parcel rather than a common value imposed on all land parcels. This addition would make control over forage growth and harvest much more realistic at a very small development cost. A further improvement in this regard would be increasing the number of land parcels allowable from the current five to perhaps 20. This increase would provide for investigation of more sophisticated grazing management policies.

An improvement of a more substantial nature involves the characterization of feed stocks in terms of moisture content. The per cent of moisture of any feed stock at each point in time would be used to convert to a dry matter basis as needed in the nutrient impact component. Reporting forage growth and feed stock production and storage on a wet basis would conform more closely to actual field practices. An additional complication, however, would be the fact that crop prices are usually dependent upon the moisture content. Some price/moisture relationships would have to be devised for each feed stock.

An improvement which would substantially increase the realism of the nutrient impact component would be inclusion of protein content of feeds on an explicit basis. The current presumption is that protein needs are satisfied when energy needs (TDN) are satisfied. In actual practice protein deficiencies are rather common among high-energy-content feed stocks; this has lead to the widespread use of protein supplements.

An improvement to the model which would increase its ease of operation for runs with long time horizons would be development of a set of decision rules which would operate as defaults to action normally taken by the user himself at a decision point. The time needed to run the model in its current form, which has no default decision rule capability, is too long for many multi-year investment questions. The decision rules which would be required to accomplish this improvement would be called into action by the user by a control variable flag set during the model initialization phase. Considerable testing would be required to develop these rules, but the increase flexibility of operation of the model would be quite welcome.

Extensions

The preceding paragraphs of this section have discussed numerous areas where the structure of the current model could be improved. The remainder of this section will review several areas of extension of the model; i.e., areas that are at present excluded from the system model. The topics to be discussed are land allocation, crop production, more subtle nutrient impacts on growth and reproduction, and stochastic variables.

Land allocation is one of the fundamental resource allocation questions which are excluded from the model in its current form. Given a particular land area with specified physical characteristics and price expectations, there are basic questions about the use to which that land, or subsections of it, will be directed. Even restricting the choice to agricultural uses still leaves open what parts are to be used for crop production, what parts are to be assigned to grazing,

and what parts are to be unused for the present. The current version of the model takes specified land parcels as restricted for grazing purposes and reads in as data specified time series of crop production; this is obviously assuming a great deal about prior management decisions concerning land allocation. These presumptions are not serious difficulties in many of the short term uses of the model; however, in longer time horizon investigations (particularily in project planning) lack of a land allocation mechanism could limit the use of this model.

Crop production is a second area where the present model could be extended to increase the scope of the system under study. This extension would naturally be more profitable (and likely mandatory) if the model were also extended to include land allocation. In any event it could be justified on its own as well. Some of the variables which could be used would be crop fertilization, chemical pest and weed control, irrigation, and the time of harvest. A necessary step to development of crop production as a component of this model is characterization of crop yield as a function of the above variables and basic descriptors of land, such as soil nutrient level, soil moisture, soil type, slope of the land, etc. It is possible that existing crop growth models could be modified and then included within this system model.

A number of areas within the realm of effects of nutrient intake on growth and reproduction are not yet included in the work of Schuette[48]. Since these aspects of the model have not been developed by this author alone, they are discussed here as extensions rather than as improvements. The following list summarizes these areas:

1. life cycle effects on reproductive potential from nutrient deprivation during heifer growth,

2. compensatory growth after feeding rates have risen above deprivation levels,

3. death rates as a function of the time-weighted nutrient deficit,

4. effects of climate of the maintenance energy requirements of cattle of various sizes,

5. calf birth weights a function of cow and heifer feed intakes during gestation,

6. calf growth rates as influenced by nutrient intake levels,

7. age of first calving as an influence over total life cycle reproductive potential.

Some of these items would be relatively simple to model, while others might be quite difficult, given the current understanding of cattle physiology.

The final area of extension to be discussed here concerns the use of stochastic variables. the current model, as has been discussed in previous chapters, is completely deterministic, with the exception of a single use of a stochastic variable in the nutrient impact model. There are likely many points where stochastic variables exist in the real system processes that are now modeled deterministically. Weather and price variables, which are exogenous, are treated as deterministic; whereas they are actually random variables fluctuating around a time-varying mean. Death rates are also random variables to the extent that disease--which strikes unpredictably--causes animal deaths. The effect of including stochastic variables would be most apparent in studies of actions in a Monte Carlo format in which it is the confidence interval of output variables which is of primary interest to the user.

VIII.4 Implementation

The final thoughts of this thesis must be directed to the use and usefulness of the product of this dissertation effort--a working simulation model of a land extensive cow/calf beef cattle enterprise. The goal of this model development has been construction of a decision making tool to allow the manager of an enterprise to make decisions on the basis of better information concerning his alternative choices. This model is not designed to replace the decision maker, but rather to assist him. This model allows the manager to explore non-traditional modes of action which in the past had to be avoided simply because of the uncertainty of the outcome. By exploring such actions via the model, the manager learns useful information which will contribute to decreasing the uncertainty involved. The cost of this information is the cost of executing the model runs desired--computer time, programmer time, and decision maker time to guide the use of the model and to make any interactive decisions required. The very large development costs of this model need not be absorbed by future users. While the predictions of the model are not without error, the author feels that use of the model by decision makers to assist and augment their traditional methods of analysis and information gathering will be worthwhile. Any final doubts about the validation of the model should be dispelled by its use in practical situations where its predictions are verified by the events which transpire.

APPENDIX

APPENDIX

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