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SOME THEORY AND APPLICATIONS
TO A MID-MICHIGAN DAIRY OPERATION

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Thomas Robert Hebert

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BEHAVIORAL AND SYSTEMS DYNAMICS SIMULATION MODELS:
SOME THEORY AND APPLICATIONS TO A MID-MICHIGAN DAIRY OPERATION

By

Thomas Robert Hebert

A THESIS

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ABSTRACT

BEHAVIORAL AND SYSTEMS DYNAMICS SIMULATION MODELS: SOME THEORY AND APPLICATIONS TO A MID-MICHIGAN DAIRY OPERATION

By

Thomas Robert Hebert

The primary questions asked concern the possible use of behavioral theory to create systems simulation models of farm businesses. Such models would be useful for management problems and for sector level policy analysis. A systems dynamics simulation model of a Mid-Michigan dairy operation was undertaken.

The modelling effort and the literature indicate that simulation models can represent much of a firm's business behavior. The potential for using these models for sector level policy analysis was found to be much less promising. Although detailed behavioral models of a single-owner farm operation are possible, their use for sector level market analysis may require more resources than are practical. Some potential and practical usefulness was found in some of the system dynamics models.

The herd management portion of the dairy model was used to examine different management issues. The results indicate that such models can be useful for the examination of on-farm management problems where behavior needs to be represented in ways not possible with the assumptions of neo-classical theory.

ACKNOWLEDGEMENTS

Dr. Sherrill Nott, a member of my thesis committee, generously contributed his knowledge and constructive insights throughout the research. Dr. Ralph Levine, another committee member, spent more time with me than I could have rightfully hoped for. He tolerated my many periods of despair over the failings of the research, and helped me see the way out of these failings or find practical alternatives. It was the willingness of my thesis supervisor, Dr. J. Roy Black, to tolerate and ask unusual questions that gave me the opportunity to undertake this particular effort. Both his breadth of curiosity and dedication to finding answers continually gave me insights into what good and exciting research can be. I am grateful to all three for their time and effort.

My thanks to the many members of the Agricultural Economics faculty at Michigan State University who explored and discussed ideas and issues with me, and in general made MSU an exciting experience. Thanks also to my friends and fellow students at MSU, who studied hard and relaxed with fervor, and who helped me to remember that our work is only a part of life.

Deep thanks must also go to my father and the other members of my family, who have been there throughout my education and this research. I hope they know how much I appreciate their support. In particular, I thank my sister Jeanne, who by opening her home to me let me share in many of the important parts of life that should not be missed, even when there is work to be done.

And finally, my warmest thanks to Phyllis Landick, without whose help this effort would never have been possible. Her commitment to loving and respecting all of that which makes me human taught me about loving and respecting myself.

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CHAPTER ONE
BACKGROUND AND THE AREAS OF INVESTIGATION

1.1 Introduction

Two assumptions lie at the heart of most theories of market economies. The first is that people make choices that are intended to have favorable impacts on their own interests or utility. The second is that people are in general rational, and that they use this capacity when they choose courses of action. Neo-classical theory of aggregate economic behavior extends these assumptions into a third; that people act as if they choose courses of actions that lead to a maximum level of utility.

The third assumption is crucial because it leads directly to much of the theory's explanatory properties, particularly if we treat the level of monetary returns to a course of action as a proxy for utility. All that is then needed to explain and predict behavior in a competitive and riskless economy is the mathematical function defining the transformation of inputs to outputs as well as input and output prices. Essentially, these three assumptions permit neo-classical theory to be broadly used as an instrument for prescribing policy actions that affect particular markets or other highly aggregative sectors of the economy.¹

Although the first two assumptions appear to be uniformly accepted by most economists, the third crucial assumption does not enjoy the same degree of assent. In particular, Herbert Simon and others in the "Carnegie"

school emphasize the significant limitations of human cognitive capacity and have developed a theory of economic behavior that does not rely either explicitly or implicitly on the assumption of maximization.² The Carnegie school's term for their perspective on human rationality and the resulting implications is "behavioral theory". An obvious limitation of behavioral theory from the viewpoint of many economists is that without the assumption of maximizing behavior, theories of market economies immediately lose much of the valuable market-wide analytical capacity associated with neo-classical theory.

The principle question being explored in this research follows from the cognitive, behavioral approach, asking:

Can the behavioral theory of the firm, with its emphasis on non-maximizing behavior and the use by firms of standard operating procedures to pursue goals, be used to meaningfully represent the decisions and actions of a particular producer of agricultural commodities?

There are numerous, potentially useful applications of behavioral theory if it can help explain and predict the behavior of individual firms. For instance, applications to farm management problems should be possible since behavioral theory emphasizes decision making processes in risky and uncertain environments. This and other applications of behavioral theory to micro-level problems are conceivable.

The farm management application deals with behavior and problems at the level of the individual or the firm. Theories of the firm also play another important role in economics. As stated above, the micro-assumptions of firm behavior in neo-classical economics lead directly to a theory of resource allocation governed by prices in competitive markets, a powerful tool for analysis of markets and sectors composed of markets. A behavioral theory of micro-behavior would be of added value if it could be similarly used as a means for sector or market analysis.

Some researchers believe that such a new theory is needed. The micro-assumptions of neo-classical theory are criticized as having little empirical base, a problem which is magnified by the impossibility of directly testing some of the assumptions.³ Leibenstein and others ask that if the micro-assumptions of neo-classical theory are not observable and testable, and if in fact the assumptions bear little resemblance to the behavior of firms in the real world, will there not be serious shortcomings to the theory of all firms in the aggregate.⁴

Behavioral theory, which is based on empirical observation and more clearly testable assumptions, would be of significant help beyond firm level problem solving if the theory could be used to generate a new theory of markets, or at least used as a tool for sector level policy analysis. If there is a need for an empirically based

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behavioral theory which could be applied to sector level problems, then we need to ask if behavioral theory can in fact represent the behavior of firms and if the results can be extended to more aggregative analysis.

The second principle research question follows from this need:

If behavioral theories prove useful for explaining and predicting behavior of individual firms, is there a potential for developing it as a tool for performing sector level policy analysis?

1.2 Behavioral and System Dynamics Approaches to Modeling

The behavioral simulation models of firms that have been created by researchers associated with the Carnegie approach bear a resemblance to expert systems, utilizing simulation models of the decision processes within firms given the behavioral constraints from the theory. The complexity of these models generally necessitates that computer simulation must be used to explore their implications and functioning.

While this is a valid method for exploring the implications of behavioral theory, it is also costly; the design and construction of such models is extremely time intensive. A method which permitted a more aggregative yet behavioral view of the firm would be of value if it could reduce the time and effort needed to construct meaningful models. One such potential method is that used in system

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dynamics, an approach which was initially developed by Jay Forrester and others at the Massachusetts Institute of Technology.

The modeling language techniques used by the system dynamics researchers, available in the relatively easily learned packages DYNAMO and STELLA appear to be suited for incorporating expert opinions about actual operating procedures and non-maximizing behavior into farm models. In the context of the two primary research questions discussed above, it would be useful to discover the answer to the following question:

Can system dynamics be of use to researchers in agricultural economics attempting to incorporate behavioral theory into firm level and sector level analysis?

This question addresses the third and final area of focus of this research.

1.3 System Dynamics and Behavioral Theory

As posed above, the three research questions involve the potentially confusing combination of behavioral theory, as defined by Simon and the other members of the Carnegie school, with the theory of system dynamics. System dynamics simulation models focus on aggregative processes within the system in question. The models attempt to capture just enough of the relevant structures of the system and the behaviors of its participants to simulate the problem of interest. There is a significant difference between this

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approach and the explicit simulation of decision processes of the Carnegie behavioral models.

Although the theoretical perspective used in this thesis is behavioral in the Carnegie sense, the modeling method used is from system dynamics. As a result, the model created will have behavioral characteristics (i.e., discrete decision processes) as well as aggregative systems aspects. The model is then in a sense neither a behavioral model nor a system dynamics model.

1.4 The Scope and Design of this Research

As this research progressed, significant changes occurred in its scope and design. The changes occurred as a result of the effort to model a dairy operation, which in itself provided a significant education on the potential for using system dynamics and behavioral simulation models to investigate firm-level behavior and the associated sector level results. In addition, certain important pieces of literature were not consulted at the start of the research.

The research initially was to be organized as follows:

- 1) Develop the basic standard operating procedures (SOP's) governing the operation of a hypothetical dairy operation;
- 2) Assemble all of the necessary production and cost data;
- 3) Use the system dynamics software to construct a behavioral systems simulation model of the dairy farm using the SOP's and cost and production data;

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4) Explore the model through simulation, asking the question "does it represent a real operation" by comparing the results to available data and the expectations of experts;

5) Consider the implications of these results for dairy sector policy analysis.

Following this design, the research began with the use of behavioral theory to design and assemble the simulation model. Well into the assembly phase, the modeling process had to be halted for even though most of the model was in place, its complexity made the numerous bugs difficult to discover and resolve. With the hope of coming back to the model with a clean mind, attention was turned to writing up various portions of the completed research.

The attempt to do the write-up, which involved going back to the literature, led to the discovery that the experience of building the model allowed more informed and better questions to be asked. The better questions led to more instructive literature and partial answers to the primary research questions discussed above.

As a result, the nature of this research changed, principally with respect to the best uses of the components of the dairy simulation model that had been constructed and completed. This thesis is organized largely according to the successive stages of learning which occurred as the research progressed so as to emphasize the effects of accumulating knowledge on the research's final shape.⁵

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Behavioral theory, as developed by Cyert and March in their seminal book, A BEHAVIORAL THEORY OF THE FIRM [9], is examined first in Chapter Two. Their book presents a theory of the multi-person firm or business organization. Although agricultural operations in general and dairy farms in particular do have important multi-person firm characteristics, the decision was made in this research to focus on a dairy operation that has a single owner and manager making the decisions. As a result, Cyert and March's theory needed some reformulation so that it could be applied to this situation. This single owner-operator adaptation of behavioral theory is developed in Chapter Three. This theory is then used to verbally and pictorially develop a behavioral model of a dairy farm in Chapter Four. Chapter Four concludes with a summary of the operational problems of assembling and debugging the complete dairy farm simulation model.

Chapter Five is a summary of relevant portions of behavioral and system dynamics simulation literature. This chapter coincides with the interruption to the modeling process referred to above and represents a summary of what the literature and the experience of building a behavioral, systems model contributes to answering research questions one, two and three. Conclusions are drawn about the ability of the behavioral and system dynamics models to represent real operations and their applicability to sector analysis.

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Given the conclusions of Chapter Five, different applications of the system dynamics methodology are seen as more practical. Chapter Six and Seven use this new knowledge to develop a problem orientated herd management simulation model. Although significantly smaller in scope than the behavioral model of the dairy farm, the herd management model demonstrates some of the problem solving capabilities of the system dynamics methodology.

Chapter Eight presents a summary of the major conclusions of this research and revisits the issue of maximization in behavioral models and economic theory.

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CHAPTER TWO
BEHAVIORAL THEORIES OF DECISION PROCESSES AND THE FIRM

2.1 Introduction

Although the neo-classical theory of the firm has been either the dominant or at least one of the major voices in theoretical and applied economic analysis for the past four decades, there has been a concurrent debate concerning the effectiveness and validity of this theory. The major concern for researchers connected with the Carnegie approach (including Simon, Cyert, March, Cohen and others) is their belief that the standard view of the firm does not reflect the actual goals, behavior and cognitive abilities of firm decision makers. These researchers also believe that neo-classical theory ignores the internal structure of the firm and its potential effects on decision-making⁶. They make a case for narrowing the focus of study to decision making processes within the firm. Leibenstein calls this general class of theory "micro-micro" theory. He emphasizes building a theory based on the actual behavior of the individual firm member. Leibenstein believes there is a potential for creating a behavioral, positivist theory of the firm, and in turn, of markets as well [18].

While Leibenstein's micro-micro theory considers the minutiae of individual behavior in multi-person firms, the Carnegie approach to firm theory draws back from the individual processes. This chapter focuses on human

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behavior from the perspective of the Carnegie school, outlining some of the basic concepts of this approach, with some contribution of related work by Heiner. Emphasis is placed on the theoretical foundations for the use of hypothesized firm standard operating procedures (SOPs) in simulation models.

2.2 Subjective Expected Utility and Bounded Rationality

According to Simon, the two primary propositions of neo-classical firm theory are that the firm seeks to maximize profits (or the discounted stream of future profits) and it operates with perfect knowledge (or knowledge of the probability of future states of the world) [9, pages 8-9]. Simon subsumes these and related propositions under one title, subjective expected utility (SEU) [28, page 12].

SEU assumes the four following conditions:

1) The decision maker has a well defined utility function which cardinally defines preferences concerning particular future events.

2) The decision maker has a well defined set of alternative actions to chose from.

3) The decision maker can assign a joint probability distribution to each possible future state of the world.

4) The decision maker chooses the strategy which will maximize the expected value of this utility function.

Simon's believes that SEU is in fact never applied in the real world, "with or without the largest computers" [28, page 14]. He cites the behavioral research on human

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subjects of Tversky [30] which concludes that even in game situations significantly simpler than real life, "human behavior departs widely from the prescriptions of SEU" [28, page 17]. Simon's conclusion is that "humans have neither the facts, nor the consistent structures of values nor the reasoning power at their disposal that would be required to ... apply SEU principles" [28, page 17].

The limited cognitive capacities of human beings means that we live in a world in which we are able to detect only a relatively small number of variables or considerations that impact on us. As a result we are forced to relate to problems as if they were contained within separable spaces. Simon's term for this constraint is bounded rationality.

Bounded rationality permits us to make decisions that would otherwise be impossible if all of the implications of every decision had to be simultaneously considered in the decision calculus. Most of the decisions we make are not of infinite time horizon, do not involve the entire range of human values or preferences, and are not interconnected with every other problem within our environment.

Bounded rationality implies that instead of trying to seek solutions which are optimal, actions will be sought that will result in performance that is good enough for the conditions at hand. Simon calls this behavior "satisficing" [27].

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The theory implies that firms will seek a level of performance which comes as close as possible to their goals, rather than an optimal level. Behavioral theory is not making a distinction between decisions that lead to a local rather than a global maximum. The focus of the theory is on the actual processes used by firms to find solutions that work within a certain range of performance. Solutions that work in a local range are different from solutions that are optimal for the range.

2.3 Applications to the Theory of the Firm

Cyert and March extend and expand Simon's work into a theory of firms in their book, BEHAVIORAL THEORY OF THE FIRM [9]. The firm in this theory is not viewed as a single unit with a single goal. The firm is seen as being made up of several different sub-units, each with its own aspirational goal and its decisions being made relatively independently of the other sub-units. The goals of the firm are multiple and changing, but they are seen as falling into the categories of inventory, production, profit, and sales.

Each sub-unit observes the performance of the firm in relationship to its own goal and treats perceived obstacles to achieving its goal as a problem to be solved. Examples of such problems are inadequate sales or market share, inadequate profits or inappropriate inventories or

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production levels. Performance relative to goals is judged on the basis of satisficing.

Simon has also developed a theory of the process used by many organisms as they search for solutions to problems, given bounded rationality. As applied to firms, the theory implies that solutions to problems are searched for and discovered sequentially. The order in which the environment is searched determines the solution discovered and the decisions made ([9, page 10], [28, page 23]).

Cyert and March consider feedback to be an important determinant of firm behavior. Feedback informs decision makers about the results of past decisions, with poor results indicating that corrections need to be made. The rules used to guide these decisions are also adjusted on the basis of feedback from past experience.

The focus of Cyert and March's theory is on the behavior of sub-units of the firm, with each unit potentially being composed of a large number of people. Leibenstein believes that this approach to firms does not move close enough to the individual and the problems of goal determination to represent a complete micro-micro theory. In particular, a more complete theory would mean work on the development of goals from within the context of sub-goals and "a theory of conflict resolution of such sub-goals" [18, page 483]. Certainly, there could be beneficial uses of such a theory, but there are also

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likely benefits to theories of the firm whose minimum level of aggregation is that used by Cyert and March.

2.4 Standard Operating Procedures

Cyert and March emphasize the use of standard operating procedures within firms. Both humans and firm sub-units generate rules of behavior to use in response to commonly experienced situations ([9, pages 100-101], [28, pages 23-29]). Simon emphasizes the combined workings of search processes involving analysis and rule governed response (rules in Simon's example being intuition) when people are confronted with novel yet familiar situations [28, page 28-29].

Bounded rationality, in Simon's search theory, leads to a sequential examination of the conditions in the immediate environment surrounding the organization. Not all conditions or possible course of action are examined, rather a course of action is often selected if it is found to provide an acceptable solution. If the problem is complicated, this decision will need to be followed by another, which also initiates another sequential search for an acceptable solution. The final solution, the result of a series of searches each concluded with a decision and a satisfactory solution, is only one of many possible final solutions. Each could be radically different from the other, depending on the order in which the environment was

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This process of searching for solutions is a demanding and difficult activity. Simon also holds that this fact, given bounded rationality, leads organizations (organisms) to remember the series of decisions made in response to past problems and utilize this series in the attempt to solve current similar problems. In this way, organizations can reduce the time and effort spent in searching for acceptable courses of action. These series of courses of action remembered by an organization are its standard operating procedures (SOP's). SOP's serve as the memory of organizations, storing the knowledge gained by experiencing the results of past searches for solutions to problems. Again, the fact that past solutions to problems were found acceptable on the basis of adequate performance rather than optimal implies that the SOP's used today will not necessarily be an approximation of maximal rules.

Heiner presents a theory of how imperfect information and the imperfect ability to use it together work to constrain the size of the set of actions economic actors can beneficially choose from (the range of activities that will be permitted in the SOP's). His own conclusion is that the theory, (termed reliability theory) "... implies the necessity of using rules and procedures to constrain individual agent's decisions and information spaces, and the dynamic flow of information between them" [14, page 2].

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He is essentially making a case for the use of standard operating procedures.

Heiner's theory is stated in terms familiar to most neo-classical decision theorists, and is an attempt to incorporate the effects of imperfect information and the potential for imperfect decisions into standard neo-classical firm theory. He applies this theory to various problems, for instance; the nature and functions of organizational structure, given such errors [14], and the necessity of adjustment delays in the actions of economic agents [15].

2.5 Summary of Behavioral View

Behavioral theories of the firm were developed because of perceived inadequacies in the neo-classical approach to firm decision making. The issue for many researchers as stated by Cyert and Hendrick, seems to be that even though "... the problem (of revising economic theory) is clearly difficult,... we wonder whether economics can remain an empirical science and continue to ignore the actual decision-making process of real firms", ([8, pages 398-412], as cited by Leibenstein [18, page 482]).

The behavioral school takes issue with neo-classicism on at least two points:

- 1) Profits are not the sole goal of firms. Goals are, rather, multiple and inter-related. A better depiction of

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the operations of firms requires a better specification of these goals;

2) Individuals and firms do not have the information or cognitive capacity to permit day to day maximization of goals. Human bounded rationality leads to a pursuit of aspirational goals, goals that are good enough given the limitations of the decision makers and the needed performance.

One of the results of bounded rationality is the use of standard operating procedures by decision makers. SOP's permit the combination of knowledge gained from past experiences with the use of analytical search processes in decision maker's attempts to find solutions to problems. The work of Heiner, which incorporates informational and decision making error to neo-classical decision theory, supports the contention that SOP's will dominate the decision making environment.

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CHAPTER THREE
A BEHAVIORAL THEORY OF THE SMALL, SINGLE OWNER FIRM

3.1 Introduction

Cyert and March's behavioral model of the multi-person firm is not directly applicable to the large number of farm operations with only one manager and a relatively small number of hired employees. The multi-person firm theory focuses on the specialized sub-units generally observable in firms, the processes by which sub-units form their goals and the impacts of these goals on firm behavior and performance. Yet, even with the multi-person orientation, Cyert and March's theory should be applicable to firms with a single owner and manager since it is grounded in models of individual cognitive capacity.

This chapter attempts to use behavioral theory to model relatively small single operator farms by emphasizing how an individual's cognitive limitations in a complex environment might lead to the development of both the goals for the farm and the means of managing it to achieve these goals. This theory is applied in the next chapter to the development of goals and management techniques for a Mid-Michigan dairy farm. These goals and management techniques are then linked in a behavioral simulation model of a hypothetical dairy operation.

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3.2 A Theory of the Single Owner-Operator Firm

3.2.1 Primary Goals

Business operations, whether large or small, exist for a reason, to fulfill a particular function or set of functions. Although the particular reason can be different for each owner or operator of each firm, one means of characterizing a particular firm is according to the means used to fulfill this function. The characterization cannot be made independent of the environment in which the business operates, yet each business' particular reason for existence determines in part the operation's orientation within its environment. One way to help determine the behavior of a particular firm would then be to ascertain the manager and or the owner's primary goals, or reasons for taking part in the business activity.

These primary goals do not need to be complex to serve as determinants of how a particular farmer would orient his operation to the world. Examples of these goals might be:

- I want to be a farmer, with a high degree of self-reliance and independence.
- I want to continue in the profession and lifestyle that my father and mother followed.
- I want my farm to be an example to my community of modern techniques and high efficiency so that I can be a community leader.
- I want to have enough income to fulfill the material needs of my family.
- I just want to generate enough income that I can keep my operation going for as long as possible.

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Although each of those goals are similar in many aspects they imply a different set of needs to be fulfilled and different ways of operating in the farm economy to achieve them.

There is little theoretical difference between the application of goal analysis to small single operator firms and the multi-person situations investigated by Cyert and March. Cyert and March hold that in a large, multi-person operation different members of the firm have different goals. These goals cannot be adequately specified by reference to some individual profit function if one accepts: 1, that people value things other than just profits; 2, that there are means other than profits to attain these valued things; and, 3, that people will to order their lives to achieve them. If utility functions include more than just profits, a more complete reference to the content of these functions is necessary to adequately predict the behavior of a person as a result of goal seeking activities.

The multi-person business with a certain degree of specialization entails information and transaction costs and therefore niches within the business that permit the pursuit of goals independent of the goals pursued by others in the firm. For Cyert and March, the fundamental question is how are the goals of the operation formed given these richly divergent utility functions and their associated complex

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The difference between this question in the context of the small firm with a single owner-operator rather than in the multi-person firm context is that for a small firm much of the entire operation can and is overseen by one person, thereby reducing many of the transaction and information costs associated with more complex systems. Where the larger firm and the small or large family farm are similar is in the difficulties in clearly establishing the goals of the operation. Perhaps to an extent even greater than that for large and small non-family businesses, a family farm will tend to have significant problems determining unambiguous goals to guide the operation. The operator of the family farm, while perhaps being the principle manager, must generally deal with the desires and needs of other members of the family since the performance of the operation can have a profound effect on every family member. Different members can have very different goals, and as a result disagreements are common. Still, assuming that these conflicts are resolved and have led to certain primary goals for the farm, the comparatively less complex institutional environment should permit an easier translation of these primary goals into operational goals.

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3.2.2 Operational Goals and Functional Areas

The above reasoning leads to the conclusion that one way to help discern the behavior of a firm is to identify its primary goals. But more is needed than knowledge of the operator's primary goals to model the behavior of the small firm since the reactions of the firm to day-to-day occurrences are also a function of the way in which the operator has organized the firm so as to attain the primary goals. Different responses are necessary for different environmental circumstances and the range of possible responses will be, at least in part, a function of the organizational structure of the firm.

One way to identify the organizational structure of a firm is to ask which specialized functions will the firm have to perform in order to meet the primary goals. A form of specialization can be thought of as occurring in the single owner farm operation. The modern farmer, operating in a complex environment must perform several complex tasks, each requiring specific skills. Behavioral theory and common sense would suggest that the way to handle all of these tasks is to separate them according to the functions needing to be performed and, to a certain extent, to treat each task or functional area as a unique and discrete operation within the farm. Good management requires that the important linkages between each of these functional areas be established and more or less continuously

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recognized no matter what function is being performed. Yet behavioral theory would also suggest that operators have a limited and finite capacity to monitor complex linkages, so that out of necessity as small a number of linkages would be preferable.

For instance, in many ways the operations needing to be performed in order to produce livestock rations are totally different from those involved in the feeding and milking of the animals, which are in turn very different from the activities associated with the purchasing and financing of machinery and buildings. In one activity the farmer is acting as a crop producer, in the other as livestock manager, and in the third as a combination investment analyst and equipment procurer. The operator must be somehow cognizant of how these disparate activities come together to form a dairy operation that suits his or her primary goals, yet in many ways each of the activities have nothing to do with each other.

The small farm can therefore be viewed as a collection of functional areas, each guided by operational goals, and linked by information and or materials so as to achieve the primary goals.

Such an organization permits a separation of the various tasks or activities performed according to their contribution to attaining these goals. This view of firms is consistent with the behavioral view, which emphasizes

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that firms have a multiple set of goals. In the multi-person firm context this translates into each sub-unit having its own goal. For the small firm it means that each separate area of tasks is guided by an operational goal (or goals).

It is not necessary to assume the farmer in question consciously decides to utilize the above described organizational system in order for that system to arise. The management of the operation will necessarily focus on performing certain tasks every day and these tasks will have to contribute, at least to some degree, to the attainment of the primary goals of the farmer. The farmer will also have to have some sense of when these tasks have been completed. This "sense" implies the presence of goals for each functional area which will be pursued, whether the farmer has explicitly chosen such goals or adopted them for some other reason (i.e. habit or tradition). Given that the day-to-day operations will be organized around such goals and that the functions of an operation consistently and distinctly follow either a daily or seasonal pattern, it seems reasonable to conceptually structure the behavior of the farmer around these distinct functional areas and goals.

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3.3 Other Applications of Behavioral Theory to Small Firms

Other components of behavioral theory can be applied in the small farm theory. The first of these is the use of SOP's. SOP's economize on the amount of thought that needs to be applied to problems or situations that reoccur frequently. A farmer could develop and use standard operating procedures in each of the functional areas of the operation as well as in the operation-wide management activities. The standard operating procedures used by a farmer would necessarily be related to the functional areas and goals referred to above. The successful identification of the standard operating procedures should make it possible to know how the farmer has orientated himself both within each functional area and within the total operation so that the primary goals can be achieved.

As for the multi-person business, small farms need feedback in order to operate successfully. Feedback is the information about the conditions and situations that face the farmer that signal the need for action or inaction. Feedback is also the process by which learning occurs, where the successes and failures of past actions indicate to the decision maker the appropriateness of the standard operating procedures in use. Of the information that the small firm operator receives in response to different standard operating procedure governed actions, he will have to distinguish between the feedback implying the need for

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action and the feedback implying a need for a change in the standard operating procedures. No attempt is made in this thesis to model the process of adaptation and change in the content of the standard operating procedures. Feedback is treated only in its role as the indicator for action or inaction within the decision set bounded by the existing standard operating procedures.

In the small firm, feedback can occur within each functional area and it can occur across all of the functional areas, indicating the performance of the entire operation relative to the primary goals. Feedback on the entire system's performance will indicate the failure or success of the firm relative to the primary goal; failure implies a problem that needs to be dealt with, and will lead to changes in behavior that must take place within the operational, organizational structure of the firm.

Feedback and the resulting responses cannot occur instantaneously and simultaneously. In the actual operation of a small or large firm a lag exists between the time of decisions and the time of experiencing the associated performance and the time when the decisions in response to this performance are made. The length of the lag and the degree of the farmer's recognition of the association between past decisions and current performance determines in part how well the operation performs. The decisions made now are dependant on the decisions made in the past, due to

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feedback, so that the form in which past performance is perceived determines to a certain degree the quality of the decisions made today.

3.4 Summary of the Small Firm Theory

The behavioral theory of the firm, as used by Cyert and March for large, multi-person operations, can be applied to small farms given the theory's emphasis on individual cognitive abilities and the resulting associated means for functioning in a complex world. Behavioral firm theory focuses on the role of goals as fundamental determinants of firm behavior. If these goals can be determined, the simpler institutional setting of the single operator farm should make it easier to specify how these goals will be expressed in the activities of the operation.

Goals can be divided into two categories, primary and operational. Primary goals define the firm's reasons for being in operation and may be used as guides in determining the organizational structure of the farm. The farm will be structured around relatively distinct functional areas which contribute to the attainment of the primary goals. These functional areas can be characterized by operational goals and SOP's.

Along with the operational goals and SOP's, feedback determines the decisions made in a particular functional area. Feedback also ties the entire system together by

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indicating overall performance, relative to the primary goals. This feedback can be used to guide decisions which will affect the entire system.

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CHAPTER FOUR
A BEHAVIORAL. SYSTEMS SIMULATION MODEL OF A MID-MICHIGAN
DAIRY FARM

4.1 Introduction

A Mid-Michigan dairy operation was selected for this research because of the ready availability of: 1, data for the many operating sub-systems of dairy farms (including, in particular, the data provided by the Michigan Telfarm budgets ([4][5][16][21][22]); and 2, numerous knowledgeable and experienced observers and practitioners that can be used as references for specifying actual operating characteristics of a dairy farm. Expert advice was drawn from agricultural economists, dairy science and management practitioners as well as dairy farmers.

No attempt is made here to create a "representative" farm, as in the use of a programming model based on data from some stratified sample of all farms [11]. The focus of this model is instead to reasonably approximate the environment and behavior of a farm based on the judgement of experts; not a model of all farms but rather a model approximating at least one farm. Neither is the model created in this research intended to serve as a representation of how a farm should operate, but again, just as a reasonable representation of an actual farm.

Following the theoretical and heuristic guidelines established in Chapter Three, the goals of the operation and some reasonable sources of feedback are established first,

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below. An appropriate set of sub-systems for the operation are established as well. Based on these goals and sub-systems, the manner in which the specified sources of feedback will affect the guidance of the system is discussed. All of this information is then summarized in causal loop diagram models of the hypothesized operation, representing both the entire operation as well as the important sub-systems. The chapter concludes with a description of the problems encountered in the attempt to create the systems simulation model of the entire operation.

4.2 Primary Goals

The primary goals of the operation are assumed as follows. The first is that the farmer desires to remain in operation until retirement. The second is that the farmer wants to milk approximately 55-60 cows with approximately the same technology during this period. The rest of the operation is scaled appropriately for this number of animals. The farmer will consider milking more or less cows, subject to maximum and minimum constraints, but the farmer essentially operates a 60 cow operation.

In association with these two primary goals, a third is assumed as well: the farmer in question needs to attain a certain level of revenues above and beyond those needed to pay for the operation. This level of revenue can be thought of as family living expenses. The primary goal, the size

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and type of the operation selected by the farmer and the associated costs and revenues, imply that the operator will seek a level of revenues that are in excess of total costs by an amount equal to or in excess of the family living expenses.

4.2.1 Other Characteristics

For simplicity's sake, the emphasis of the operation is on producing milk. Two other possible substantial revenue producing activities, cash grain and livestock, are not to be included in this operation. Any revenues from the sale of livestock are not the result of intentional livestock production for sale; revenues may be generated by the sale of any replacement livestock in excess of that needed to maintain the desired milking herd size. There are no sources of income from off the farm.

Another characteristic of this operation that is assumed for simplifying purposes is that only the roughage component of the dairy ration is produced on the farm. All grain concentrates are purchased off the farm. Only two kinds of roughage are grown; haylage and corn silage. Both are stored in above ground silos.

This characteristic of producing only the roughages on the farm, and producing concentrates off-farm, is observable on some farms in Michigan. But it is more common for dairy

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operations to be growing their own grain, if not for sale off the farm then for on-farm consumption. The complications and the associated problems that would be created for a behavioral model of the joint economic decisions of producing both grain and milk were considered to be too great relative to the realism that would be lost in the model by assuming only milk production.

These goals and characteristics are arbitrary, given the range of types of operations found in central Michigan. Yet many mid-Michigan operations are in fact similar to the farm proposed above, both in the operating conditions and the goals attributed to the hypothesized farmer. These similarities permit the determination of reasonable operating procedures based on expert opinion.

4.2.2 Feedback with Respect to the Primary Goals

The primary goal can be summarized as "remain in the business of producing milk with a 50 to 60 milking cow operation until the time of retirement, provided that adequate family living revenues are generated". One piece of information that can serve as an indicator of performance relative to this goal is expected cash flow. If the operation has the desired number of animals and all of the associated necessary functions generating costs and revenues are being performed, any shortfall in anticipated net revenues indicates a need to change.

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As indicated by the theory of the small firm developed in Chapter Three, making the primary goals operational involves combining different SOP's in a satisficing environment. The day to day SOP of meeting short-term cash flow needs can reasonably be considered to lead the farmer to use cash flow position to determine if the farm is meeting the primary goals. If the farm has the qualities desired by the farmer and meets today's demands for cash, then the primary goal has been met, at least in the short-run. The task is then to create an SOP that extends this daily success into the future. One indicator of future success is projected cash flow over some planning horizon. Almost all of the cash flow information needed to make this projection is available from information about daily operations.

This indicator is not proposed as the best way to guide the system, but rather one indicator that could be used given the implications of behavioral theory. Although discussions with dairy experts did not conclusively point towards this or any other primary performance indicator, the general consensus was that such an indicator could conceivably be used by a real farmer. The point of placing this hypothetical dairy farm in a simulation model is in part to determine if such an indicator could permit a farm to succeed under real world circumstances.

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If expected net cash flow falls short of the level needed for family living expenses, a change in the operation is needed. Defining the set of actions available to the operator in such an instance is the last step in making the primary goals operational. Two likely areas of intervention are in the primary revenue generating component, milk animals, and in the primary source of expenditures, the feed ration.

The general consensus among the experts and practitioners consulted is that farmers do respond to relative changes in input and output prices. Unfortunately, no one was willing or able to say conclusively if farmers respond directly to prices, or through changes in some other indicator like net cash flow, or how the response actually occurs. Most were willing to concede that one of the potential indicators that could be used by farmers to monitor performance is cash flow.

One relatively common response to difficult financial circumstances observed among farmers is to slow down the rate at which input suppliers are repaid⁷. The practice amounts to obtaining an unsecured loan and reduces immediate cash flow pressures. Farmers may also, at times, be willing to marginally alter the size of the herd (housing and milking capacity permitting) in order to improve cash flow position or take advantage of short-term changes in prices.

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Many dairy farmers are reluctant to significantly change the content as well as the relative mix of their feed in response to changes in input or output prices. This tendency would seem to be due to the uncertain effects of such changes on output per cow, as well as the significant investment of time and effort in learning how to handle and feed a new ration. An existing SOP relative to the type and quantity of ration appears to have a large degree of inertia, meaning that it will change very slowly, if at all, in response to standard changes in prices. Skinnerian behavioral theory would say that in order for the ration SOP to change in response to input price changes, the farmer would have to consistently experience that such changes improve net revenue, yet the other factors leading to resistance against changing the SOP would tend to make the "experiments" necessary for such experience unlikely.

The willingness to change herd size is in contrast to the unwillingness to significantly change ration content. At first glance, this makes sense; the time and effort needing to be expended in order manage a herd increased or decreased by five or ten percent is less than that to change the specific mix of a ration and the associated feeding practices for the entire herd. Presumably, farmers can and do marginally modify the quantity and timing of an established ration mix, and this behavior could be modeled.

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Potentially, all of the interventions discussed so far, as well as others, such as delaying the purchase of machinery, could be included in a simulation model of a reasonable operation. In this proposed model, the farmer is assumed to have only a gradually changing SOP governing ration content with the changes limited to increases in the total quantity of ration, as historically promoted by the agricultural extension service and adopted by other producers. Changes in ration type and mix may result from relative changes in prices, but inclusion of such influences do not appear necessary to simulate a reasonable operation.

The action set available to the farmer in response to changes in expected cash flow is limited in this model to marginal changes in the number of milking animals. The actual change in herd size to be made by the farmer is determined by the number of animals the farmer believes would lead to the highest level of expected net cash flow. The operator is assumed to handle short term cash flow pressures by reducing the rate of repayment of accounts payable, but the long-term direction of the farm is not affected by this decision.

4.3 Subsystems and Operational Goals

The hypothetical dairy farm in this study has a set of distinct functions that make up the operation of the total system. Following the conceptual means for organizing a

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single operator firm given in Chapter Three, Table 4.1 presents the functional areas of the operation, hereafter called subsystems, as well as the primary operational goals of the subsystems.

Each of the proposed subsystems contributes to the primary goals of maintaining the operation at a certain size until retirement while maintaining a certain level of cash for living expenses. As can be seen in Table 4.1, most of the subsystems and their associated goals contribute "operationally" to the primary goals, for example: herd management maintains the desired number of milking animals and their replacements in good health so that they can produce milk, and thereby produce cash; labor management attains and manages the level of labor needed to operate the various subsystems of the farm and produce cash, given the level of labor desired by the owner/operator; and, short term cash management deals with the payment of accounts as well as attaining and paying for any short-term loans so as to permit the continuance of daily operations.

The linkages between these subsystems is either materials, costs or information. Roughages produced or concentrates purchased are physically passed to a ration feeding operation, which is then converted to milk, while the costs of producing or purchasing the ration are monitored and dealt with by the cash management subsystem.

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Table 4.1: A Summary of the Farm's Subsystems and the Associated Goals

SUBSYSTEM	GOALS
Herd Management	Ascertain and maintain the desired herd size. Raise and or purchase replacements.
Ration Production	Produce the desired quantity of roughage and concentrates.
Milk Production	Determine and feed the appropriate ration. Maintain adequate milk per cow.
Labor Management	Hire the needed quantity of labor. Maintain the quantity of operator labor within the desired range.
Capital Purchases	Purchase equipment and buildings as needed.
Debt Management	Pay-back long and intermediate term debt. Alter repayment rate if excess cash is present.
Short-Term Cash Management	Manage cash to maintain a positive balance.

The informational linkages between the subsystems serves as the source of feedback. The central feedback information is the relative levels of variable and fixed costs and revenue which are used to determine the expected cash flow. Feedback affects the system in two ways. The first is within a subsystem as various decisions are made. For instance, the number of replacements to maintain, or the quantity of capital to obtain, or the amount to be paid to input suppliers. The feedback on performance of the

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subsystem is compared to the relevant operational goal to determine the necessary response.

The second, over-riding effect of expected cash flow sets much of the course for the system. If the response to poor expected performance is limited to marginal changes in herd size, the operation cannot change either too drastically or quickly.

All of the materials, costs and information linkages are discussed in more detail in the following section, which presents causal loop diagrams of the entire dairy farm system.

4.4 Causal Loop Diagrams of the Dairy Farm Model

4.4.1 Introduction

The causal loop diagram is a descriptive instrument that can be used to depict the fundamental components of a system as well as the causal interactions linking all of these components. A causal loop diagram consists of three things; the variables or components of the system (represented by the circles), the linkages and direction of causality between the components (the lines and arrows), and the relationship between the causally linked variables, defined as either positive or negative (+ or -). The system changes over time as the variables simultaneously increase,

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decrease or have no affect on the relative size of the other variables.

The number of variables and interconnections in the behavioral model of the entire farm make its causal loop diagram excessively large, detailed and difficult to either read or explain. For this reason, the diagram of the entire system is not presented. The causal loop diagrams of portions of the dairy operation presented and discussed below are much easier to interpret and understand while still demonstrating the important aspects of the entire system.

4.4.2 The Entire Dairy Operation

The model is organized around the functional subsystems that operationally help the farmer reach his primary goal. The primary goal is expressed in two variables (model variables are identified in the text by all capital letters), CASH NEEDED FOR FAMILY LIVING and DESIRED OPERATION SIZE AND TYPE. Four relatively distinct groupings of subsystems needed to reach the primary goal can be identified in the model. The first is the policy setting subset which examines expected cash flow relative to CASH NEEDED FOR FAMILY LIVING to determine the desired number of milking animals. The second grouping includes the subsystems for the production of milk, herd management, ration production and purchases, and the use of hired and

operator labor. The third grouping is the short-term financial component, including variable costs of production, farm revenues, and cash flow position which itself includes accounts payable management and payments on long, intermediate and short term debt. The final grouping is the capital, debt and assets subset which provides an accounting record of debts and liabilities for the dairy farm.

4.4.3 Cash and Expected Cash Flow

A separation is made in this model between the current cash flow position and the current expected cash flow. The fundamental difference between these two variables is the way in which accounts payable are treated. Figure 4.1 depicts the accounts payable loop.

VARIABLE COSTS, entered exogenously in this detailed view, has a positive effect on ACCOUNTS PAYABLE, meaning that as costs go up, so will ACCOUNTS PAYABLE; the converse is also true. REVENUE has a similar effect on CASH. As ACCOUNTS PAYABLE increases, so will the rate at which accounts are paid out (ACCOUNTS PAYABLE OUT). This, in turn will decrease the ACCOUNTS PAYABLE and CASH due to the negative or inverse effects on these two variables. ACCOUNTS PAYABLE and CASH also determine the level of CASH FLOW PRESSURE experienced by the farmer. As CASH FLOW

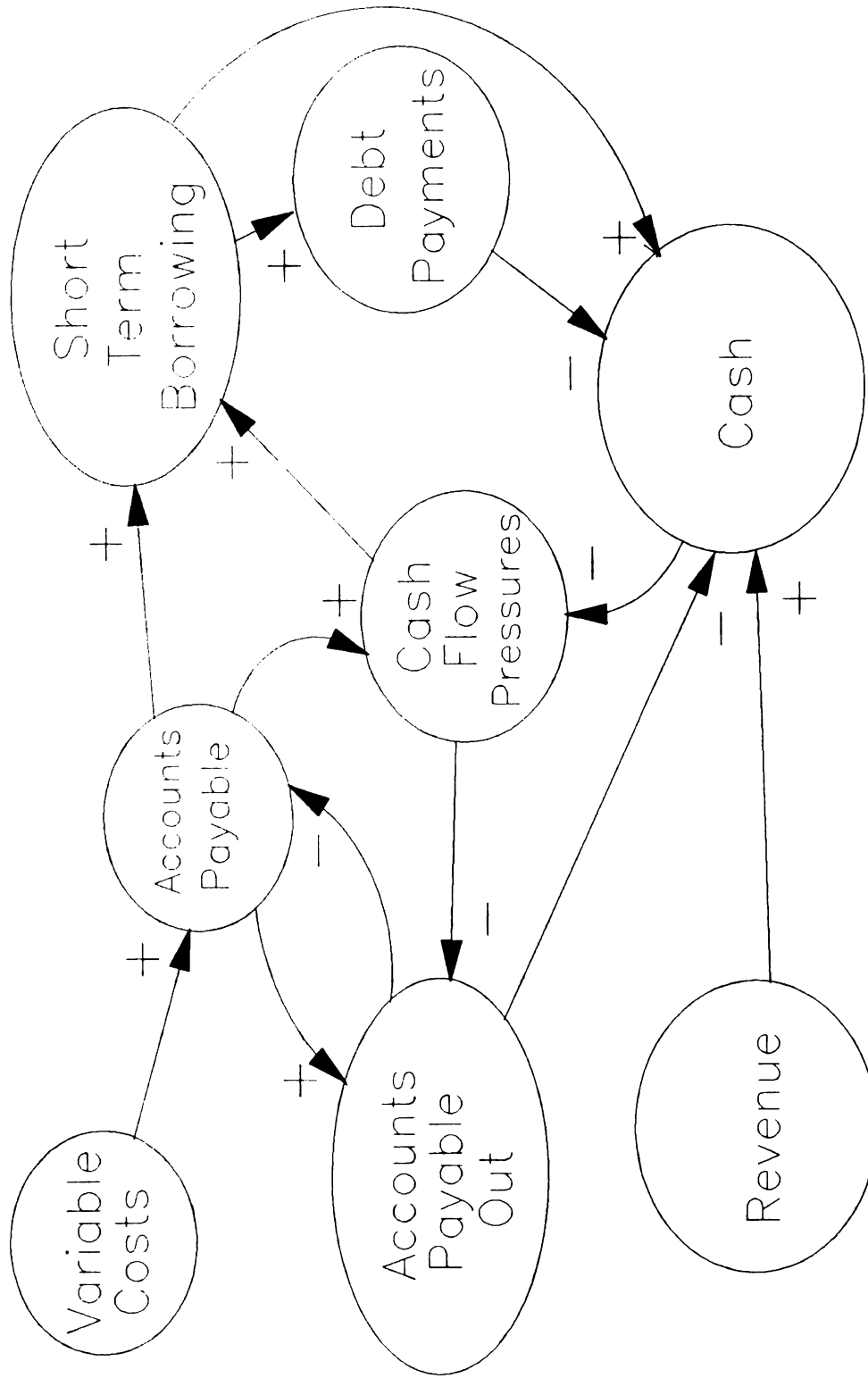


Figure 4.1: Short-Term Cash Position/Accounts Payable Loop

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PRESSURE increase beyond a certain level, SHORT TERM BORROWING will have to occur. The result is an increase in CASH which will decrease CASH FLOW PRESSURE.

Another balancing mechanism for CASH FLOW PRESSURE is its impact on ACCOUNTS PAYABLE OUT. As CASH FLOW PRESSURE increases, ACCOUNTS PAYABLE OUT will decrease, thereby decreasing the rate of withdrawals from CASH which again leads to a decrease in CASH FLOW PRESSURE. But as ACCOUNTS PAYABLE OUT decreases, the rate of decline in ACCOUNTS PAYABLE will also decrease, which will tend to maintain CASH FLOW PRESSURE. SHORT TERM BORROWING will increase DEBT PAYMENTS, which also increases CASH FLOW PRESSURE through effects on CASH.

4.4.4 Revenues

The loop representing the generation of revenues is presented in Figure 4.2. The STOCK OF ANIMALS and RATION determine MILK PRODUCTION. The STOCK OF ANIMALS (along with SOP's not depicted here) determines the SALE OF EXCESS OR CULL STOCK. MILK PRODUCTION and the SALE OF CULL STOCK, along with the associated prices, determine the level of REVENUES. REVENUES (which feeds into the cash loop, see Figure 4.1) feeds back onto the stock of animals through the expected cash flow loop, depicted here by the dotted line. The dotted line represents another set of variables which characterize the expected cash flow process. The

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farmer is assumed to be making EXPECTED CASH FLOW calculations for increases, decreases and no change in current herd size.

Each EXPECTED CASH FLOW calculation for the different herd sizes are ranked, with the highest dollar value indicating the most advantageous herd size. The increases or decreases are limited by an SOP that allows changes in herd size of only five and ten percent. The expected cash flow calculation is an extrapolation based on current revenues per cow, variable expenses and DEBT PAYMENTS. The needed quantity of hired labor changes for differing herd sizes and the changes in hired labor costs from herd size to herd size are the primary source of per cow cost difference among the various calculations. This herd size becomes the DESIRED MILKERS figure. The question mark at the link between EXPECTED CASH FLOW and STOCK OF ANIMALS indicates the dependency of the effect on the outcome of the ranking.

The farmer's analysis of EXPECTED CASH FLOW is independent of the ever-present problem of short-term cash management. While dealing with short-term cash problems involves changing the rate of payout on ACCOUNTS PAYABLE or borrowing operating funds, EXPECTED CASH FLOW analysis uses current information about costs and revenue to make a strategic decision with an outlook beyond this month.

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4.4.5 Variable Costs

The Variable Costs loop is presented in Figure 4.3. The STOCK OF ANIMALS determines the level of RATION PRODUCTION AND PURCHASES; these two variables lead to MILK PRODUCTION. The three together determine the TOTAL LABOR required for the farm. The STOCK OF ANIMALS also determines the quantity of HIRED LABOR through an SOP not depicted here. The TOTAL LABOR required minus the HIRED LABOR determines the quantity of OPERATOR LABOR.

Five variables then contribute to the VARIABLE COSTS level; STOCK OF ANIMALS (herd management costs), RATION PRODUCTION AND PURCHASES, MILK PRODUCTION, HIRED LABOR and all of the associated INPUT PRICES. As VARIABLE COSTS go up, so will ACCOUNTS PAYABLE. VARIABLE COST increases will also likely lead to decreases in EXPECTED CASH FLOW, although this effect may be ameliorated by alterations in expenses due to differing levels of HIRED LABOR. The loop is closed by linking EXPECTED CASH FLOW to the STOCK OF ANIMALS, with the sign of the causality being dependent on comparison of relative advantages as explained for the previous diagram.

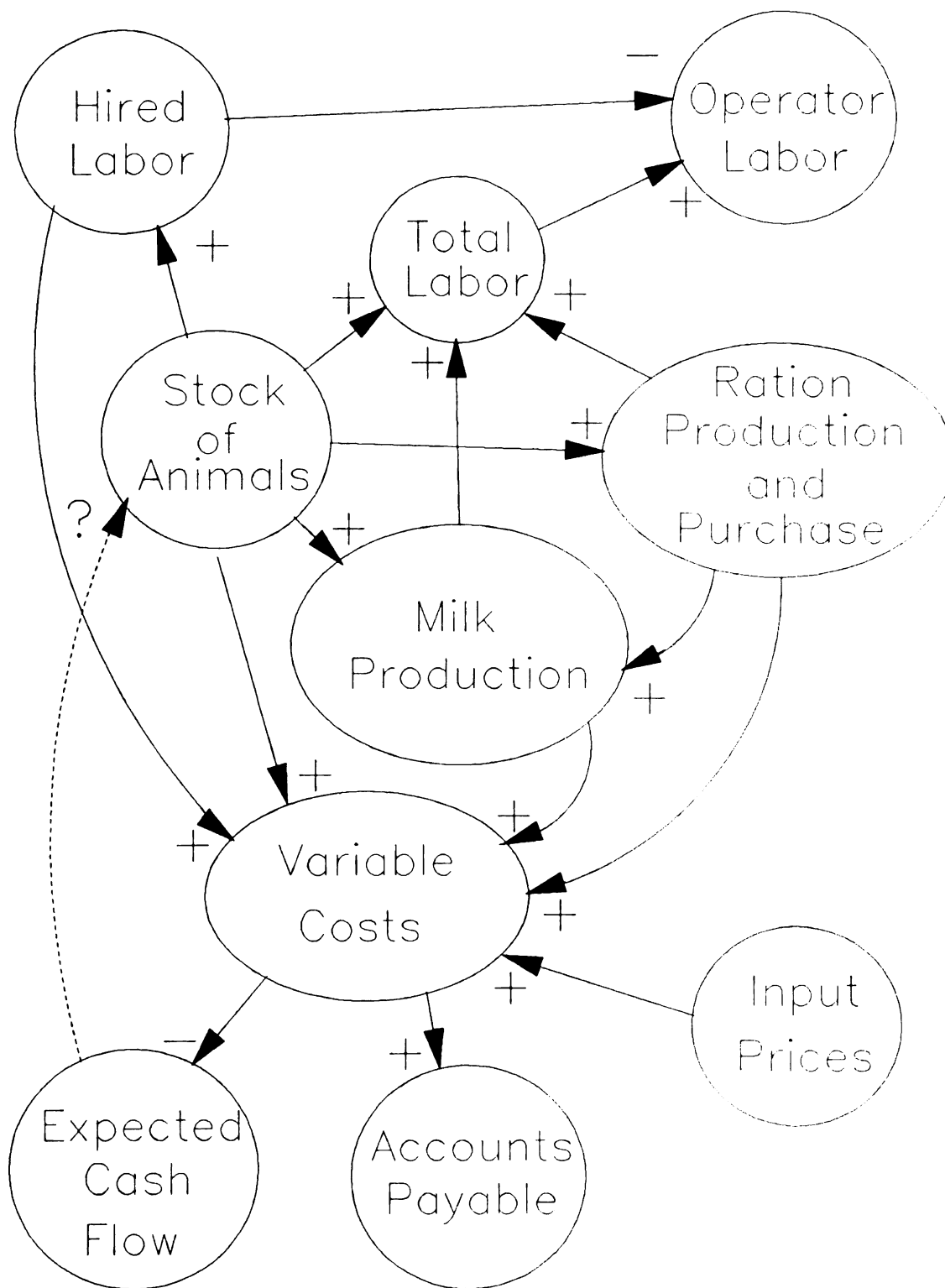


Figure 4.3: Variable Costs Loop

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4.4.6 Capital, Debt and Assets

The final subsystem to be depicted is the Capital, Debt and Assets Loop, as shown in Figure 4.4. Purchases of LONG AND INTERMEDIATE TERM CAPITAL occur at the inception of the operation and when the items wear out. Borrowing occurs to finance the purchase of the items, leading to the principle and interest payments which constitute LONG AND INTERMEDIATE TERM DEBT. SHORT TERM BORROWING occurs when there are significant CASH FLOW PRESSURES (see Figure 4.1), which also leads to the accumulation of SHORT TERM DEBT. Both of these sources of debt combine to form DEBT PAYMENTS, which are withdrawals from CASH. ASSETS is the sum of the monetary values of CASH, CAPITAL and STOCK OF ANIMALS.

The ratio of debts to assets serves in this model as the principle indicator of credit worthiness. While this ratio is commonly used by the credit industry to judge credit worthiness for short and intermediate term loans, long term loans (for buildings and land) are often judged on a more comprehensive basis (such as cash flow analysis to insure sufficient cash for repayments, or the net present value of the investment in conjunction with cash flow analysis). In numerous cases, this quantity of detailed financial information is not readily available so that lenders often resort to an enumeration of the assets on the farm to indicate the quantity of collateral

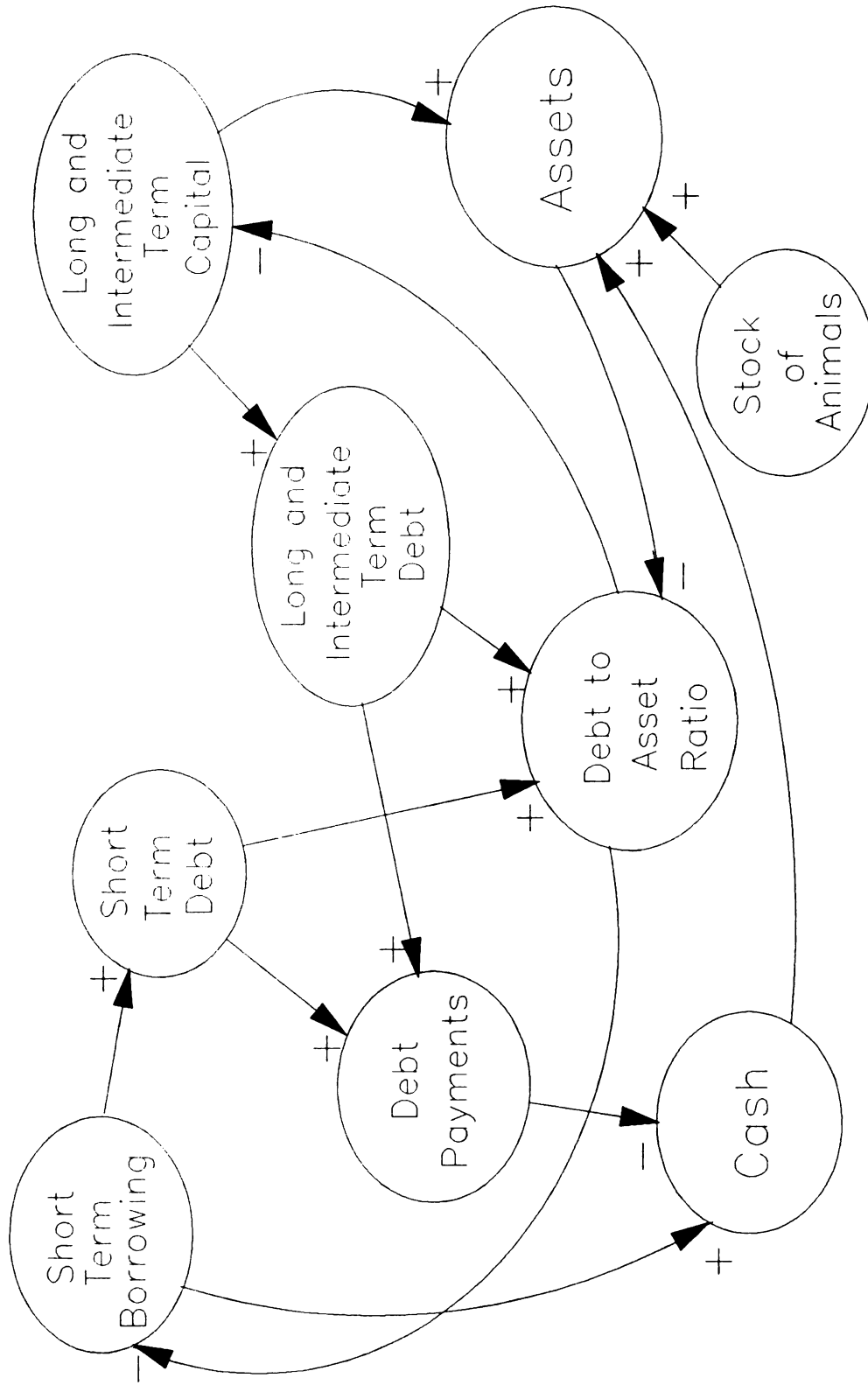


Figure 4.4: Capital, Debt and Assets Loop

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present⁸. For the sake of simplicity and given the real world use of collateral information for long term debts, the DEBT TO ASSET RATIO is used to judge all three debts.

As the DEBT TO ASSET RATIO increases beyond a certain threshold, less borrowing of all three types of CAPITAL can occur. The availability of credit decreases continuously as the ratio increases beyond this threshold until the point is reached where no borrowing can occur. DEBT PAYMENTS will continue to be withdrawn from CASH which will lead to a continuation of CASH FLOW PRESSURES, leading to a reduction in the ACCOUNTS PAYABLE OUT rate (see Figure 4.1).

4.5 Summary

The expected cash flow calculation is a source of feedback which directs the course of the operation with the primary goal being the level of CASH NEEDED FOR FAMILY LIVING expenses and the DESIRED TYPE AND SIZE OPERATION. The causal loop diagrams of various components of the entire system are presented to detail the primary operations on the farm. Behavior in the cash management subsystem is significantly affected by the experience of cash flow pressures. The availability of credit for long and intermediate term capital as well as short term operating funds is dependent on the debt to asset ratio. This ratio serves as an indicator of ability to meet repayment responsibilities.

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4.5 The Systems Simulation Model of this Hypothetical Operation

The simulation model of this behavioral model was constructed using the system dynamics language STELLA, a package designed for use on APPLE's MacIntosh personal computer. The simulation model is derived directly from the theory of the single-owner firm and the behavioral model detailed above. The operation is organized around the subsystems that permit the farm to operate day to day, with the most dynamic sources of feedback being short-term cash availability, expected cash flow, and the effects of labor requirements.

The model is not completed. The problems with the model are too numerous and the model too detailed to permit its completion within the time constraints of this thesis. Table 4.2 is a summary of the subsystems in the models as well as the number and type of variables in each subsystem. (Definitions for the types of variables in a system dynamic's model are given in Appendix One.) Both the total number of variables and the number of state variables indicate that this is a relatively large model. In comparison, Meadow's Commodity Cycle model for hogs has approximately one-sixth the number of state variables and one-eighth the total number of variables ([20], a description of Meadow's model is given in Chapter 5).

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Table 4.2: The number of variables, by type, in the dairy farm simulation model, as compared to Meadow's model. (a/)

Subsystem	State	Rate	Auxiliary	Total
Herd Management	6	10	39	55
Ration production ...	2	2	13	17
Milk Production	0	0	3	3
Revenues and Costs ..	0	0	28	7
Land	0	0	7	7
Short-Term Cash Management	7	11	11	29
Capital, Debt, Assets	12	18	27	57
Labor	2	2	18	22
Expected Cash Flow..	2	2	32	36

Total Per Type	31	45	178	254

Total Per Type in Meadow's Model	5	5	23	33

(a/) cite Meadows Book				

The fact that Meadow's model is so much smaller than the dairy farm model is partly a reflection of Meadow's skill as a systems' modeler. Yet, this dairy model was intended to explicitly capture a more complex reaction and decision process, and the size of the model is a reflection of this extra degree of complexity.

Major difficulties remain in obtaining a defensible specification of some crucial variables in the dairy model. Independent of the likely objections that some researchers may have to the use of expected cash flow as the primary source of feedback, and marginal changes in herd size as the principle method of strategic management in the model,

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problems remain in the herd management, short-term cash management and labor management subsystems. In the herd management subsystem, the current specification of the culling decisions of young cows and mature cows likely causes a misrepresentation of the relative mix of young and mature milkers on a dairy operation. More complex culling decision processes need to be incorporated.

In short-term cash management, a better specification is needed for the impacts of changes in cash flow pressures on the rate at which accounts are paid out. Difficulties remain in the labor subsystem, primarily in the SOP's governing the hiring of labor and the total labor requirements for the dairy operation. These, and other specifications and technical problems need to be resolved before a working model of an entire farm can be completed.

As discussed in Chapter One, these problems were initially not considered major enough problems to prevent the completion of the model within this research's time constraints. At the time the problems were first encountered attention was turned to writing up completed portions of the research. The writing process as well as the experience of building the model led to more informed and better questions, which led to the discovery in the literature of partial answers to the primary research questions. The literature explored and the conclusions drawn from it as well as the experience of constructing the

above simulation model are presented in Chapter Five.

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CHAPTER FIVE
SOME THEORY AND APPLICATIONS OF
BEHAVIORAL SIMULATION MODELS

5.1 Introduction

Models, economic or otherwise, are caricatures of a real world situation or system, and as such are always going to be "unreal" in significant respects. The issue of concern is whether or not the model is real enough to be of use in its applications to or exploring the problem of interest. Deciding upon the degree of reality that a model requires is then a crucial step in assessing its quality. This decision requires some classificatory scheme which can be of help in determining how the models should be judged and by what criterion. A two-way scheme for viewing behavioral simulation models is offered below as one way for viewing behavioral simulation models.

With these considerations in mind, the literature describing some of the important behavioral and systems dynamics models is reviewed. The literature provides some answers to the primary research questions developed in Chapter One. The literature, and the attempt undertaken in this research to model a Michigan dairy operation (detailed in Chapter Four) also indicates ways in which behavioral theory, system dynamics and neo-classical microeconomic theory may be jointly used in market-level analysis. These and other conclusions are discussed at the end of this chapter.

5.2 Judging the Validity of Simulation Models

Although other classification schemes are certainly possible, behavioral simulation models of real and unique markets and firms can be considered as belonging to one of two classes: 1, a theoretical model with many of the same properties relevant to validity and specification of any other theoretical model; or 2, an attempt to forecast with some degree of precision the performance of the system in question. But the distinction between theoretical model and forecasting model becomes blurred when simulation techniques are used. This is because any simulation model of the real world is essentially a theory of the market or firm, so that a model intended to simulate or forecast actual performance has some of the same characteristics as the theoretical models.

Given this somewhat blurred distinction between these two classes of models, an issue arises as to how to judge the validity and appropriateness of the model in question, particularly when the model belongs mostly to the theoretical class, rather than the more quantitatively precise representational class. This issue becomes somewhat slightly more difficult to resolve, in theory, when computer simulation is used to evaluate the implications of the model's structure and assumptions.

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Computer simulation of theoretical models is a relatively new entrant to the field of tools available to the social science investigator. The fact that the computer needs and uses quantitatively measured variables to execute theoretical models often leads to the assumption that the simulation results need to be judged on some absolute quantitative basis much like the way we check the math we use to balance our checkbook. Either the calculated results are correct or they are not.

But the fact is that computer simulation of theoretical models is no more than another system of symbols or language for expressing the set of relationships or conditions that the theoretician wishes to explore. For some sets of relationships and conditions the computer simulation language is perhaps the only suitable means available for the exploration.

Cyert and March view computer simulation as a "...fourth language in which the assumptions of a theory can be expressed and its conclusions derived" [9, page 315]. The other languages available are ordinary prose, pictorial geometry and mathematics.

Although simulation models can serve in many roles, one of Cyert and March's primary uses of computer simulation is essentially as a tool for the building of behavioral theories of firms. The models constructed are not intended to be used for forecasting, but rather they are used to

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investigate the consequences, in theory, of a particular set of assumptions and hypotheses.

Given this distinction, the issue of obtaining a properly identified system of variables so as to permit unbiased parameter estimation, is not necessarily an issue with respect to judging theoretical simulation models. In the application of assumptions to create theoretical structures, the primary issue is the logic and consistency of the model, as well as its linkages to our sense of what is a reasonable representation of the real world.

There are no absolute tests of the logic, consistency and the degree of correspondence between theoretical models and our own sense of what is reasonable. These are more properly decided on the basis of informed argument amongst experts. In other words, an evaluation of the specification of any theoretical model, no matter what language it is expressed in, is a matter of debate amongst students of the subject matter. When we judge a researcher's description of a thought experiment they performed to try and solve a particular problem we don't ask if the parameters in the model are properly estimated. We ask if the conditions and approximate magnitudes of relationships make sense and are relevant. In many ways a theoretical simulation model is nothing more than a complicated thought experiment conducted in a cybernetic environment.

The issue of unbiased parameter estimation does appear when these theoretical models are adapted or applied to actual systems or markets in an attempt to recreate the actual performance of the system in question. One of the commonly used means for judging the performance of any simulation model, behavioral or otherwise, is to compare model output for some historical period to that performance actually observed. While a model that tracks history well is considerably more credible than one that does not, there is no guarantee that the individual parameters in such a model are necessarily correct. Models can mimic a system's past performance without actually having important relationships in the system properly specified and quantified, meaning that the test of workability is not interchangeable with the statistical/mathematical conditions and tests for bias.

But theoretical simulation models are not necessarily seeking to achieve a representation of an actual system. The implications derived from the solving or execution of any theoretical model, whether simulation based or mathematical, are not forecasts, and as a result theoretical analytical models should not be judged by the criterion applied to forecasting models. Simulation models could be more effectively constructed and their validity judged if the distinction between theoretical and forecasting models is kept clearly in mind when the models are built as well as

evaluated by outside observers.

5.3 Some Literature on Behavioral Simulation and a General Theory of Markets

One of the stated purposes of researchers using simulation models (see below, Cyert and March, Lyneis, and Meadows) is to develop a set of assumptions into a theory that is broadly applicable to many situations, as in the way the neo-classical model is used as a theory for all markets. As a test of the general model, the basic structure developed is applied to a real world system.

Leibenstein believes that the Carnegie approach (for present purposes, the system dynamics models are placed in this same class) really serve as models of a specific and unique environment and that they are not general enough to become a truly coherent micro-micro theory. He cites others who have come to the same conclusion [18, page 483]. If he is correct on this point, it is not necessarily a condemnation of the Carnegie class of models, just a call for more care to be used when identifying the exact applications where these models will be the most useful.

The ability of any of the behavioral approaches to achieve a general theory of markets, including the work of Leibenstein, appears to be severely limited by the present state of human behavioral theory. The models proposed will only be as universal as the universality of the assumed behavior. As long as we disagree over what constitutes

universal or general market behavior the behavioral models would seem to be best used in the analysis of specific markets or firms, where the relevant behavior is more likely to be defensibly specified.

Even if the behavioral applications are not able to achieve general market results, it remains possible that a behavioral model of a specific market could be used as a tool in sector level policy analysis and policy making.

5.4 The Literature of Behavioral Simulation Models

5.4.1 Cyert and March; A Duopoly Model

A general model is constructed by Cyert and March [9] which attempts to describe the price and output behavior of firms in an oligopoly. The properties of this model are also explored in the context of a duopoly.

The basic model deals with three sets of decisions and their interactions with each other through feedback. The three decision areas are output, price and sales.

The output decision is based on a smoothed inventory and production goal. The proposed level of needed inventory is set by this unit within certain limits defining excessive or inadequate levels. Proposed production is then the forecast for sales plus the difference between proposed and current inventories. Any changes in production must be within some experientially determined upper and lower limit. The inventory and the production decision are

therefore inter-related although the goals are set separately.

The price set by the firm is a result of the following: a relatively complex process involving a comparison between actual profits achieved in the last period, given the price, and the profit goal; any changes in the costs of manufacturing the good; and any changes in the long-run price behavior of competitors. The pricing mechanism is analogous to that used by manufacturers in Balderston and Hoggatt's model (see below).

The sales decision is not treated in as much detail as the previous two. In response to changes in performance of various units relative to their goals, pressure is applied to change the level of sales. Sales pressure can result if there is a decrease in organizational slack in the firm as a whole, or a direct result of inadequate profits or market share. The sales unit is also able to exert pressure on price setting within the firm, with any serious changes in the price position of the firm relative to competitors' being immediately corrected (within the imposed profit goal / price limits). Undesired changes in sales level or market share has a more lagged effect on price.

The marketplace within which all firms interact is also defined in the model. Market demand is a function of the weighted average of all firms' prices, sales effectiveness pressures, sales promotion expenditures and an exogenous

factor. The firm's market share is a function of relative sales effectiveness pressure, relative price level, relative promotion expenditures and lagged market share.

In the two-firm simulation model application of the above general model, a multiple, step-wise regression analysis is applied to the results from several simulations to attempt to determine the greatest sources of impacts in the system. Four dependent variables (firm price, inventory, market share and profit) are made a potential function of twenty-five others - the final equations contain approximately eleven variables.

Examples of independent variables seen to consistently have a strong effect are as follows:

- 1) The proportional increase permitted in production (the upper bound).
- 2) The extent of price response to changes in competitor's price.
- 3) The required markup to maintain profitability.
- 4) Propensity to modify price in reaction to failure on the profit goal.
- 5) That firms with adequate slack in their operation, which permitted an improvement in operations when the firm experienced input cost changes, tended to be the lower priced firms in the market.
- 6) Ability to modify the sales goal relative to current profits.

It is not clear why the multiple regression method of analysis is used. Aside from the serious problems with the validity of the results of step-wise regression, it seems that unless the four equations are estimated as a simultaneous system, biased and inconsistent coefficient estimates should result. As in the discussion of Balderston and Hoggatt (below), the lack of concrete sensitivity analysis here may be a function of the lack of appropriate software. In either case, it may have been more reasonable to perform ANOVA analysis to obtain the type of results desired by the authors.

It would seem that the analysis used demonstrates in a non-definitive sense that the system of assumptions and theory yields performance that could be expected in an economic system. These results also demonstrate that the model is "viable" in the sense used by Balderston and Hoggatt (see below).

5.4.2 Balderston and Hoggatt; A Decentralized Market System

A computer simulation model was created by Balderston and Hoggatt [1] [2] to permit the analysis of a system of relationships that they believed are too complex for standard mathematical analysis. They are attempting to explore the dynamics of a market system, composed of different sets of economic actors and linked together by relatively complex behavior.

The market system to be simulated is the West Coast lumber industry. The industry is seen to be composed of three classes of vertically linked firms. Goods move from manufacturers, through wholesalers, to retailers. The wholesalers act as the intermediaries between the manufacturers and retailers; information about supply and demand meets at the wholesale level. Cash flows from retailers and wholesalers to manufacturers.

The primary goal of the research is:

"... to show how limits on market information, decentralization of market decisions, and institutional alignments affect and are affected by economic forces." [2, page 183].

To achieve this goal, the authors use an eclectic approach to representing the firms in this system as well as the operations of the market. The authors feel that their approach is new. In their own words:

"We had no general theory of market processes to serve as a precedent for applications; rather, we attempted to use the occasion of a single, empirically based study for exploring the potential domain of such a general theory." [2, page 183].

Although the primary goal of the study is to provide general analytical results, the authors recognize that the claims of generality are subject to dispute, based on "... consideration of the conceptual elements of the model and of the way in which they have been linked together". [2, page 183].

In the simulation model, the three sets of economic actors trade amongst themselves without a centralized

trading area. Trade partners are discovered through a decentralized search for suitable price and output offerings.

The empirical study of the lumber industry found the distribution of firms in the industry to be roughly two manufacturers to one wholesaler to three retailers. The number of firms in each of these classes is limited in the model to a maximum of thirty to fifteen to sixty, using the same proportion as that found in the real market.

Manufacturers have two primary functions; produce goods and set offer prices. The quantity of goods produced by any one manufacturer is determined by the quantity of output needed to return their inventories to some desired level, relative to expected sales. Expected sales are a four market period moving average of past sales.

The price offered by each manufacturer is not based on profit maximization. Maximization would require knowledge of how own changes in price would affect total demand as well as the offer prices of other manufacturers. The pricing rules are also not based on attaining (satisficing) some aspiration based profit goal, since such a decision also requires the capability to predict the effects of own price changes on relative profitability. The authors decide to establish a price setting rule which is based on feedback from the effects of past pricing decisions on profits. In

an indirect way, this price setting rule attains a certain type of satisficing result. The feedback from most recent experience is given the most weight.

The retailers have three primary functions; establish the retail price of the good, determine the price which they are willing to pay for goods, and determine the quantity of goods they would like to purchases.

The retailers set a retail price that will result in profit maximization. The retail firms face a downward sloping demand curve for their final product. The retail firms are not able to affect demand through sales promotion so that the demand curve is kept constant throughout the simulation. The retail firms are monopolistic competitors, due to local isolation.

Retailers set bid prices in essentially the same manner as that used by the manufacturers, based on experience of past bids and the associated profit,

The quantity of goods the retailers would like to purchase is that needed to return their inventories to some desired level relative to expected sales. Expectations for future sales are generated in the same way they are generated for manufacturers.

Wholesalers do not carry any inventory of goods. They serve solely as a facilitator of trade between potential trading partners. The wholesaler searches among manufacturers and retailers for close matches in offer and

bid prices. Once potential partners are discovered the wholesaler communicates with the two potential partners to try and confirm the sale. The sale will be confirmed if the offer and bid prices of the potential traders are approximately the same.

Since one of the goals of the research is to examine the effects of the costs of information on the performance of the system, the model is simulated with exogenously set levels of message costs for each communication between wholesaler and potential trader. The unit message cost varies from zero to some arbitrarily set level.

The range of trading firms that the wholesalers will search is set exogenously from run to run - the two possible states being either all retailers and manufacturers explored in a random fashion or a subset of all potential firms. The content of the subset is determined by past experience with the cost of achieving an agreement between potential partners. The subset will tend to be made up of retailers and manufacturers who, in the past, the wholesaler was able to bring together for the lowest relative cost.

A simulation is divided up into "market periods", with each period divided up into a "market cycle". At the start of each market period the manufacturers and retailers all set their desired prices and the quantities they would like to trade. Each market cycle consists of the search for

potential trading partners. Cycles continue until all demand for the period is met. One market period is equivalent to one month with each simulation lasting up to sixty months.

The performance of each firm is measured with a financial balance sheet. Firms that are bankrupt at the end of the market period are forced out of business and if the average profits of all firms in a particular class are above some threshold level, new firms in this class are permitted to enter. Firms also can change size as a simulation progresses as they respond to increases or decreases in the quantity of goods they are trading and the quantity of working capital available to them.

The authors state that one of the first tests of the "correctness" of the model is to test its "viability", a term which in a limited sense is synonymous with the commonly used system dynamics concept of model validation. A model is considered viable, in the authors' use, simply if the model can be simulated. The assumption seems to be that given that their focus has been to realistically represent portions of the system, if the assembled portions continue to produce and trade output through a simulation run, then the model has a certain degree of viability (and validity).

The step of systematically examining the simulation results to determine if the simulated system actually demonstrates behavior expected from the real system (as used in system dynamics, see below) is not explicitly taken. In their defense, though, the authors report on numerous runs of the model with an eye towards spotting results that would be inconsistent with their knowledge of the real system.

The model is used as an experimental environment for examining the effect of changing certain crucial variables in the system. Several runs are performed with each run varying only in the unit message cost of communication and the type of preference ordering set used by the wholesaler (a random set or one determined by experience). Under these different conditions, the authors attempt to measure the degree of market efficiency, the degree of match or mismatch between supply and demand and the effects of the system on the size distribution of firms.

Efficiency is defined here as the relationship of potential wholesaler revenues at the start of the market period to those revenues actually received. At the start of each market period the authors construct an aggregate manufacturer's supply curve, given their inventories and offer prices. A similar aggregate demand curve is constructed for the retailers. These two schedules imply a certain level of potential revenues (call it A_1) for

wholesalers if they were to match suppliers and retailers with a minimum number of communications. At the end of the same market period, actual wholesaler revenue (A_2) is calculated. The market efficiency measure is $e = A_1 / A_2$. The more efficient the market, the closer e is to one, the less efficient, the closer e is to zero.

Wholesalers do a relatively efficient job. The calculated average values for different simulations range from .81 to .92, with the simulations differing on the size of the unit message cost as well as the type of wholesale preference set.

The authors also examine the ability of the market to match supply with demand. Using the same start of market period supply and demand schedules calculated above, it is possible to ask if the potential quantity to be supplied by manufacturers is greater, less than or equal to that demanded by retailers. Supply is found to be in excess in all types of simulations with excess being greater under a random preference set compared to the experiential preference set.

The authors find that the operations of the system result in a skewed distribution of the size of firms within their respective classes, even though all firms within each class are given the exact same characteristics at the start of each run. No firm differs according to entrepreneurial ability or resource availability so that the skewness

results purely from the operations of the market. The higher the unit message cost the greater the degree of skewness. More skewness also occurs when the wholesalers's search for trading partners is guided by past experience of low cost agreements rather than a random survey of all potential traders.

The authors do not state this, but one of the implications of these results is that there is a tradeoff between the advantages of the random preference set, which results in a less skewed distribution of firm sizes, and the fact that the random preferences persistently yield a greater level of excess supply.

In a separate report on this research published in 1962 [2], the authors discuss the current methodological limitations imposed on the analysis of the causal mechanisms in simulation models. The authors use their own statistical indicators of correlation between variables (such as non-parametric tests) in the model, but they are not able to perform the kind of sensitivity analysis that would lead to reasonably conclusive proof of causality. This limitation appears to be more a function of the software that the authors had available for model execution rather than the degree of complexity of the system. Today's software may permit adequate sensitivity analysis of this model.

In conclusion then, Balderston and Hoggatt have built a simulation model using non-optimizing goals in a standard operating procedure dominated behavioral setting. It appears that their research has shown that such a model can replicate the functions and economic performance of a single firm as well as those of an entire market.

5.4.3 Summary of the Implications of these Studies

The two models described above, created by Cyert and March, and Balderston and Hoggatt represent some of the potential for behavioral simulation modeling of firms. Without providing what may be considered irrefutable evidence, it seems that their models have represented the operations of firms without a singular profit goal, but rather with many goals and without maximization or perfect information. The question remains, can this approach be used for sector analysis?

The answer would seem to be a strongly conditional yes. Both models could be used to evaluate different policies, such as the effects of changing input and output price levels, or permitting more instability in these prices. Balderston and Hoggatt's model also could provide a means for examining many other significant questions. For example, how would the system perform if there is a difference in the unit message cost between wholesalers? The same question might be what if some wholesalers had better

access to information about the trading position of manufacturers and retailers? Or, how would the system perform if the price discovery process was changed to a centralized auction market?

The potential for using this approach for sector analysis must be questioned because of the great quantities of time and expense that are required to construct these models. Balderston and Hoggatt estimate that the dollar cost of their research is approximately \$96,000.00, or \$350,000.00 in 1985 dollars (roughly seven man years of work) [1, pages 280-281]. The cost of their research includes the two years spent by one of the authors in doing the empirical study of the industry, which became his PhD dissertation.

One of the reasons for this expense, which is also the source of the primary constraint upon using the behavioral approach, is that the "general" theory is not readily applicable to specific markets. Each time a model is built of a specific firm or market system, large costs will be incurred when the empirical evidence is gathered and the model specified. Every system specific model is a new theory and building this theory is a time consuming process. This expense can be contrasted with the relative ease that the neo-classical theory of firms and markets can be applied to a specific situation with aggregate data. There would appear to be a tradeoff between the richly

complex questions that can be asked of the simulation models described above and the associated expense of the modeling effort. It would be interesting to compare the costs of the Balderston and Hoggatt study with those incurred for a similar neo-classical regional programming model, such as the 1963 study of the distribution of dairy and related resources in the Lake States region [11].

Given that the state of technology for simulation model construction has improved significantly since the time of the behavioral studies described above, it seems reasonable to assume that the cost of projects similar to either of the above models, undertaken today, could be greatly lowered.

Before exploring in more detail the question of this methods applicability to sector analysis it would seem instructive to ask why has computer simulation been used so little to explore and expand the theory of the firm. A review of the publications in the major economic journals for the past seven years reveals no research of the type presented above. This is in contrast to the statements by some that the advent of computer simulation would spawn a great deal of theory building about the inner workings of the firm (see, [7] and [9, Appendix B]).

Naylor and Vernon [23, pages 463-464] present four reasons for the lack of applications of simulation to the development of firm theory. First, such models have a

strong empirical base resulting in the same difficulties outlined above. Second, many more fields than just economics are necessary to adequately develop these models. The potential theorist, in this mode, must have a grasp of decision theory and theories of group behavior, in addition to working knowledge of the contributions of such disciplines as psychology, sociology, political science and business administration. Studies requiring such a broad cross discipline approach are tremendously difficult to undertake and complete.

The third criticism is that not enough attention has been given to developing effective experimental design in computer simulation applications. The authors state that "economists have had little or nothing to say about the problem of designing simulation experiments with models of the firm" and for this reason, the results "have proven to be inconclusive and difficult to interpret". Any generalizations made on the basis of such models are viewed with skepticism on the part of economists, in sum resulting in "questions about the usefulness of computer models of the firm" [23, page 464]. It is not entirely clear how to take this criticism. In part, the source of the confusion about the validity of the technique may be the result of the causes outlined earlier in this chapter; theoretical models are different from forecasting models and that the two types of models can be easily confused in the simulation

environment.

The confusion may also be due to the extensive complexity present in many firm models, leading to difficulties in sensitivity analysis and model validation. This type of confusion may be avoidable if researchers establish clearer purposes for the models and use theory that is constrained to a degree of complexity that will permit adequate sensitivity analysis, given the capabilities of the software.

Naylor and Vernon's final point is that simulation models have been applied to "cases where more traditional methods of analysis may have been more appropriate" [23, page 464]. Their point is made in reference to sector level problems. It seems clear that traditional methods of analysis could not have achieved the type of results given by Balderston and Hoggatt or those of Cyert and March. Still, Naylor and Vernon cite the work of Machlup and others which makes a case for when maximization of goals in a partial equilibrium environment can achieve satisfactory results [23, page 464].

There very well seem to be instances where Machlup's point is true, even in the context of simulation models. There are other possibilities for using a behavioral approach in a simulation environment that incorporates elements of maximizing behavior, without incurring the same vast costs of the Balderston and Hoggatt's study. Naylor

and Vernon's final point will be discussed in more detail at the end of this chapter, after examples of these alternative behavioral models of firms have been explored.

The alternative modeling approach examined below is an application of the system dynamics approach, as developed by Forrester [13] and others at MIT. The system dynamics approach, as summarized by Lyneis, is as follows:

- identification of specific problem behaviors
- construction of a model of the structure and policies creating the behavior
- developing an understanding of how the structure and policies create the behavior
- designing policies that improve behavior
- test alternative policy responses under different plausible scenarios [19, page xiv]

The focus of the approach is on the interaction of the behavior of the system's actors with the structure of the system. A computer simulation model is used to perform this analysis.

5.4.4 Meadows; A Dynamic Commodity Cycle Model

Meadows research goal is to examine commodity systems and attempt to model the regular cyclical fluctuations commonly found in these systems. The primary objectives are to "... derive a general dynamics model of the structure underlying long-term commodity production cycles, to validate that model, and to determine it's implications for the design of commodity stabilization policy." [20, page

2]. In the system dynamics approach, "underlying structures" are seen as resulting from the real world lags imposed on materials, information and the adjustment of behavior.

Although Meadows does not state it as such, the economic actors in the model are implicitly assumed to behave in an essentially neo-classical fashion. Meadows uses standard assumptions concerning the shape and slope of both the firm level supply and the consumer demand curves as well as assuming that the actors are rationally acting to maximize a utility function dominated by economic returns [20, chapter four].

In an attempt to create a generalizable analytic framework, a non-commodity specific model is constructed which emphasizes structural relationships common to many commodity systems. System behavior is considered to be rooted in changes in various "state" or "stock" variables which accumulate or decline over time. The major state variables in the general commodity system are production capacity, commodity inventories at the wholesale level and the price expected by producers.

Production capacity is causally linked to capacity desired on the part of producers, which is itself causally linked to their price expectations for both the commodity and the major inputs to the production process. Inventories are linked to the amount of capacity being utilized by

producers and per capita consumption of the commodity. A biologically or technologically determined delay exists between production capacity utilized and the completion of the production process. Per capita consumption is a function of commodity price which is determined in the short-run by wholesalers who set prices in response to the movements of actual inventories relative to some desired level. Expected price at the producer level is a weighted average of the actual commodity price. Expected price then closes the system's loop by providing feedback to producers as they generate productive capacity.

Meadows specifies values for the variables in this structure using published price elasticities and appropriate biological and technical delays for hogs, cattle and broilers. Three commodity specific models are therefore created. The simulations of each of these models resulted in cyclic production patterns with periods and magnitudes similar to those actually observed for all three commodities.

Sensitivity analysis of the hog model is performed. Some of the areas examined are changes in supply and demand elasticities and the level of inventory coverage desired by wholesalers.

Making the supply elasticity of producers more elastic results in increased instability in productive capacity. Meadows does not analyze the source of this instability but

it is likely due not only to the obvious reason, the increased response rate of producers, but also to the effect of such responses on the movement of more pork through the system, causing more price instability. Ultimately, this instability feeds back into desired productive capacity. (An examination of the relative movement of all variables in the system is possible given the nature of the software used to construct the model. It is not clear to me why Meadows did not explore these loops in more detail, although he may have not seen this as necessary to achieve the broader goals of the study).

Keeping the original supply elasticity and reducing the demand elasticity for pork results in even more unstable productive capacity than that seen for changes in the supply elasticity.

Meadows also lowers the inventory level coverage desired by wholesalers by 50 %, which in essence makes the retail price more sensitive to short-term changes in supply or demand. Productive capacity also becomes extremely unstable under these conditions. Meadows notes that any commodity stabilization policy intended to work at the producer level will likely be thwarted if the same policy results in reduced desired inventory coverage [20, page 76].

Meadow's own conclusions are that sensitivity analysis can be used in these models to reveal potential areas of focus for policy intervention. The implication is that for certain classes of commodities, the general commodity production cycle model could be readily adapted for use as a policy analysis instrument.

5.4.5 Lyneis; Corporate Planning and Policy Design

Lyneis [19] examines the potential for using a system dynamics model of a corporation as an aid to corporate planning and policy design.

Lyneis does not use a behavioral/organizational theory of firm operations that focuses on the interaction of goals within the firm, as used by Cyert and March. The corporation is viewed as one unit with one primary objective, although the objective used in this case is not profit maximization but rather producing enough output to satisfy demand. Viewing the corporation as one unit also implies that the decisions made by the corporation to achieve this objective are made without any of the difficulties foreseen by Cyert and March. The use of lags in the perception of changes in the environment as well as lags in decision making time in Lyneis' model may serve as a valid and straightforward approximation of the decision making process within the corporation.

The study is divided into three parts: 1, a general overview of the applicability of system dynamics to corporate problems; 2, development of a basic and general corporate simulation model; and 3, applications of the model, with variations, to specific problem areas.

Lyneis places the general corporation to be modeled in a monopolistically competitive market. The corporation's output is heterogeneous enough to permit it to be distinguished from the other competitors in the market. The competitors remain constant in their policies, so that changes in this corporation's behavior does not result in an alteration of the other firms' basic operations.

The general model of the corporation is based on, as in Meadows, the significant stock variables in the system. The model is essentially an inventory model with many of the auxiliary variables being determined by the information implied by the relative levels of the inventory states.

The customer order rate, an exogenous or endogenous variable, depending on the run, sets in motion a process that is linked eventually to finished inventory for sale. The customer order rate signals to the corporation the quantity of finished inventory needed. This information compared to the actual finished inventory determines the needed production rate. The corporation treats the needed production rate as its current objective. The production of finished goods does not occur instantaneously but rather it

takes a certain amount of time determined by the manufacturing process as well as the constraints imposed by the available stock of inputs to the production process.

The stock of inputs is determined in nearly the same fashion as the finished inventory. The current average of the production rate (the averaging process implicitly involves a delay in perception) determines the corporation's needed parts inventory. Parts are ordered if there is a shortage, with a time delay occurring between the time of ordering and parts arrival.

This basic model is used to demonstrate how the decision rules related to the perception of and response to needed finished inventory and needed parts inventory are dominant dynamic links that can create instability or inefficiencies in this simple system.

In part three of the study the model is applied with some modifications to a number of corporate problems, such as:

- 1) the use of trend analysis of demand information;
- 2) interactions with company suppliers;
- 3) interactions with customers and competitors;
- 4) interactions with labor;
- 5) the dynamics of financial control;
- 6) the dynamics of capacity expansion;
- 7) the dynamics of professional resource expansion.

A brief discussion of the third problem area is given below

to demonstrate application of the model.

In order to permit the examination of the problems surrounding interactions with customers and competitors, the customer order rate is made partially endogenous to the performance of the firm. The customer order rate responds to changes in two variables: 1, the length of the delay between the time the customer orders finished inventory and the time it is delivered (delivery delay); and 2, changes in the sale price of the finished good.

The delivery delay occurs because the firm does not anticipate changes in customer order rate. The unexpected demand causes product completions to lag behind desired production. The firm responds by increasing the production rate, which is itself held back by the limitations of available inputs to production.

Two of the scenarios run by Lyneis should indicate the model's usefulness. One scenario examines the reactions of the firm when the customer order rate is linked to delivery delay. The other to the firm's performance with both a delivery delay and price response. The firm is forced to react to the shock of an increase in the customer order rate, as would occur if a major competitor was suddenly unable to supply goods to consumers.

In the first set of runs, the lags imposed by the firm's inventories and response time endogenously causes the customer order rate to fall below the level before the

shock occurred. The production lags result eventually in a decrease in market share.

The firm could alter the policies governing the responses to such demand changes and hopefully retain more market share. The firm could either increase the rate at which it recognizes a change in demand, thereby increasing the rate at which it changes desired production or it could carry more inventory. The first policy change would still result in the lag due to the shortage in parts; the second means tying up more capital in inventory than perhaps the firm really would like. The trade-offs between maintaining market share and maintaining liquidity are therefore able to be examined in scenarios of this type.

In the third scenario, with both a delivery delay and price response, the system becomes unstable, with the degree of instability a function of the speed with which the firm alters its price due to inventory coverage changes and the elasticity of demand given to consumers.

With demand changes being linked to both delivery delay and price, the model permits an evaluation of the tradeoffs between the costs of carrying inventory, the costs of lost market share and the costs of instability.

One potential shortcoming of Lyneis' approach to examining the performance of the firm is that the firm's competitors are permitted to respond to changes in demand as if they were not constrained by any structural and

behavioral lags. It seems more realistic to expect that unexpected shocks would be felt by all competitors, creating a dynamic interaction between all firms and the customers. The observed changes in market share would likely be considerably different under these market conditions. The market model created by Balderston and Hoggatt (see above) placed firms in such a context and their approach may be applicable here.

The work of Lyneis is similar to that of Meadows' in that they are both system dynamics approaches; they focus on the impacts of the stock variables in the system, which for many businesses means inventories. But, the work of Lyneis is also significantly different from Meadows. Lyneis places much more emphasis on the actual operating procedures within the firm and does not give the firm a profit maximizing goal.

No discussion is given in Lyneis of the relationship of the operating structures used in this research and those of the real world (Meadows explores this relationship to his model). The lack of such discussion makes it hard to gauge the validity of the theory behind this model. If, though, the theory is relatively valid, then it seems reasonable to conclude that the standard operating procedures used in this context do permit a good representation of the performance of a real firm.

5.5 Conclusions: Simulation and Sector Analysis

Cyert and March made an explicit statement in their book concerning how they perceived their behavioral theory of the firm in relation to neo-classical theory. They state:

"The (neo-classical) theory of the firm, which is primarily a theory of markets, purports to explain at a general level the way resources are allocated by a price system. To the extent that the model does this successfully, its gross assumptions will be justified. However, there are a number of important and interesting questions relating specifically to firm behavior that the theory cannot answer and was never developed to answer... Thus, many of the attacks on the theory of the firm are not so much proper critiques of existing theory as they are suggestions for the development of a theory appropriate to a different set of questions. Ultimately, a new theory of firm decision-making behavior might be used as a basis for a theory of markets, but at least in the short-run we should distinguish between a theory of micro-behavior, on the one hand, and the micro-assumptions appropriate to a theory of aggregate economic behavior on the other. In the present volume we will argue that we have developed the rudiments of a reasonable theory of firm decision making. Our arguments for the utility of the theory in developing a theory of markets are, at least at the moment, more modest." [9, pages 15-16]

The same general conclusion is reached by Cohen and Cyert in 1975, when they state that for a certain class of problems in aggregate sectors, the micro-assumptions of neoclassical theory may be perfectly acceptable ([7, page 51] as cited by Leibenstein [18, page 482]). Simon also seems to leave open the possibility for the adequacy of the neo-classical model when he states that:

"Their (economic models) veridicality and usefulness cannot be judged from the fact that they satisfy, formally, the Subjective Expected Utility assumptions. In evaluating them, it is critical to know how close the postulated

utilities and future events match those of the real world." [28, page 16].

Leibenstein senses a procedural difficulty here, noting that "If a theory will not predict the behavior of a firm, can it predict the behavior of a collection of firms?" [18, page 482].

This question deserves a great deal more discussion than will be pursued here, but it seems reasonable to conclude that when all firms are examined in an aggregate, static sense, the shape of the implied supply and demand curves do approximate, at least to a rough degree, those expected from neo-classical theory (even the behavioral models presented above incorporate in a behavioral sense, relative price information and price response). This price responsiveness will be present, it appears, even if decision makers are not maximizing and may in fact be satisficing. This point does not deal with the issue of how much of a degree of rough approximation of real firm behavior will be necessary to permit the neo-classical results to be accepted with confidence.

In the context of the current discussion of sector analysis, given the above remarks, the following points can be made:

- 1) There is a difference between a general theory of markets, a general theory of firm behavior and a set of theoretical approaches to firms and markets that can be of

significant help in constructing simulation models of specific, unique firms and or market systems. This last distinction makes the usage of theory analogous to the application of principles learned in a discipline such as engineering, where no single method covers all of the designs needing to be constructed.

2) Even though Cyert and March's theory is not intended to replace the neo-classical theory of markets, they have used their theory to develop a simulation model of a hypothesized two firm market. They have represented a firm with their theory and they have placed it in a market governed by similar principles. The primary limitation of their approach is the degree of complexity in their model, making it extremely difficult to construct and difficult to analyze. These problems make their method of limited use to other researchers in sector analysis.

3) Lyneis presents a system dynamics model of corporate behavior that is less complex than Cyert and March's but may in fact capture as much of the structure needed to analyze the behavior and performance of corporations. The greatest limitation of Lyneis' model is that it places its corporation in an environment of firms that do not reflect the same operational realities, making the results of firm's interactions in markets of questionable relevance.

4) Balderston and Hoggatt's model essentially deals with this limitation by thoroughly re-creating the operations and

relationships of an entire market. Their model seems to be potentially the most fruitful for sector analysis, although their model may be of such great detail and expense that their approach also holds little promise for practical research. It is not possible to determine by a priori reasoning exactly how much of this expense could be avoided today with the use of better software and hardware, but a similar project could be expected to cost less.

5) It would be possible to place a collection of Lyneis type firms in a Balderston and Hoggatt environment. This approach may be just as complicated as the Balderston and Hoggatt exercise and therefore subject to the same limitations. A model of this sort would be of use for sector analysis.

6) Meadows creates a model of an agricultural commodity sector that relies primarily on neo-classical assumptions of firm behavior, but places the actors in an environment which reflects material, biological and informational delays to replicate the cycle in productive capacity and prices experienced in this sector. The sector level policy applications seem clear if one accepts the validity of the model; the relative effects of price stabilization policies can be ascertained, given the different goals and structural constraints of the different actors in the system.

7) A synthesis of Meadow's approach, which is an aggregative system dynamics model using some aspects of neo-classical assumptions, with the Carnegie emphasis on the micro-behavior of firms, may be able to take advantage of the relative ease of application of a Meadows model and the real world benefits of behavioral theory. The synthesis could take the form of establishing a sector or sub-sector model using the general system dynamics approach of Meadows and then imbedding in this model, at crucial points, sub-models incorporating more explicit behavioral theories. The crucial points may be those observed in the Meadows-type model to be of singular importance to the operation of the sector, given the policy question at hand.

In comparison to all of the modeling efforts reviewed, the last suggestion given above appears to hold the most promise of utilizing behavioral theories of the firm in a simulation environment without spending a vast amount of time, effort and money. The system dynamics emphasis on identifying the problem behavior and including only as much structure as needed to capture the relevant behavior greatly reduces the scope and complexity of the models.

Such a model could be conceived along lines similar to those used by Meadows; making use of the neo-classical assumptions for simplicities sake where relevant and then focusing in on a specific node in the system, applying more explicit behavioral theories. The research effort could be

divided into two broad stages, the system dynamics stage, including sensitivity analysis searching for sources of the undesired performance, and the behavioral modeling stage if it is found that the model could be improved by such an application. This model seems more consistent with the goals of a PHD dissertation and cannot be undertaken in this current research.

5.6 Answers to Research Questions

The first two research questions from Chapter One can now be answered with the information learned up to this point. The first research question asks if firms can be reasonably characterized in simulation models with non-maximizing goals pursued with SOP's. Although the results of the simulation models reviewed above are not conclusive, they provide strong evidence that behavioral simulation models can be used to represent firms in this manner. The second research question asks if there is a potential for using the behavioral view of the firm to perform sector analysis. The literature and the modelling effort undertaken here indicates that the detailed behavioral simulation models are costly and time consuming and may be useful for sector policy analysis only if a large number of researchers and resources can be committed. Still, the technique can be seen as holding promise for less costly research if used in combination with other

theories, such as neo-classical market theory.

The third research question is, can a system dynamics modeling method be used to create behavioral simulation model of firms and by association contribute to the analysis of sectors? This question remains unanswered because my own model was never satisfactorily completed in STELLA, although a model of the entire firm does not appear to be impossible to achieve. Although the entire firm model was not completed, the behavioral models of significant portions of the dairy farm do indicate that it is a satisfactory method for representing important areas of farm operations and could possibly be used to solve farm level management problems. Chapter Six and Seven presents one of the dairy farm's subsystems, the herd management model and is evidence for this conclusion.

CHAPTER SIX THE HERD MANAGEMENT SIMULATION MODEL

6.1 Introduction

The reason for constructing and presenting this herd management simulation model is significantly different from the original reason for the design and construction of the entire farm simulation model. The entire farm model was intended to help answer the primary question of the thesis; can behavioral simulation models reasonably represent the functions of an operation, without maximizing behavior and perfect information? This question was answered in large part by the literature (see the conclusions to the previous chapter). One of the other primary questions being asked in this thesis (research question three, from Chapter One) concerns the ability of the system dynamics software STELLA to be used to design and construct behavioral models for use in firm level and sector analysis.

Although it was found to be provisionally possible in Chapter Five to perform firm level and sector analysis with behavioral models, it could not be determined whether STELLA can be used to build a behavioral model of an entire farm. This is because a behavioral model of the hypothetical dairy operation was never completed in STELLA; in part, this result implies that the answer to the question would be no. In fact, this question remains unanswered given that the skill level and time constraints of this researcher contributed to the failure to obtain a working model.

The design, construction and simulation of this herd management model cannot be used to answer research question three. This is because the herd management model does not incorporate enough dynamic economic behavior to permit an extension of its simulation results to conclusions about entire farms. The goals of building and simulating the herd management model are less ambitious:

- 1) Can STELLA be used to model a specific part of the dairy operation?
- 2) Can this model rely on the use of SOP's to guide the operation?
- 3) Could such a model, which focuses on specific problems in the herd management area, be of possible use to agricultural economists?

6.2 Model Overview

The primary goals of this herd management subsystem are to maintain a sufficiently healthy population of milking animals and replacements while pursuing a program of selection of animals for replacements that will tend to improve the quality of the milking herd. The goal of herd improvement could be pursued by either using selective breeding and culling of replacements on the farm or by purchasing high quality animals at any stage of maturity.

The herd in this model is divided into four age groups. The rationale behind the divisions stems from considerations of the different stages of herd management and the associated change in management problems. The

stages tend to represent ages of animals that are treated in a manner different from all of the other aged animals in the herd. The general differences tend to reflect death rates, feeding rates and differences in culling decisions.

The four main age groups are: 1), calves, from age zero to four months; 2), heifers, from age five to twenty-seven months; 3), young cows, which enter this stage upon their first freshening at approximately 28 months, and; 4), cows, which enter this stage when the second birth occurs.

A general description of each of these age divisions and the types of decisions being made is given below. A complete listing of the equations representing this subsystem along with a detailed description of each of the equations follows.

6.3 Calves

Calves enter the herd as the stock of animals of adequate age give birth. A good rule of thumb is that a mature cow will give birth once every thirteen months⁹, although this average can be improved if the farmer's breeding program is effective. The first four months of life are the most crucial for the replacement animal since this is the time they are the most susceptible to diseases that can lead to death [12]. Death losses in this age group can be as high as forty-seven percent, but a commonly used figure is fourteen percent [12].

Given the focus of the farm on producing milk and not livestock for sale, only the animals needed as replacements for milkers are kept on the farm. All surviving male calves are sold. All surviving females in excess of the number needed to replace the loss of mature animals due to death and the standard cull rate are also sold.

Calves remain in this stage for four months, by which time they have passed the critical point for susceptibility to disease. At the end of four months, calves are either sold or move into the heifer stage.

6.4 Heifers

Heifers are animals from age five to twenty-seven months, which is the age that on average, the cow will first give birth and begin milking¹⁰. Animals are held in this stage in this model to simplify the simulation of the decision to cull a young animal due to milking or reproduction problems (see the detailed description of the model equations, below, for further discussion of this separation). The decision to cull these animals can only occur once they have given birth and have started to milk, hence the separation of the young animals into non-freshened and freshened animals. Heifers are subject to death loss during this stage, with average losses being seven percent a year for all animals from age five months and older¹¹.

6.5 Young Cows

These are the cows which have freshened for the first time and have begun their first lactation. The operator is assumed to examine these animals, looking for reproduction problems or poor milking characteristics. The assumption is that, on average, five percent of all young cows are culled each year due to these "standard" problems. Young cows are therefore removed from this stage for three reasons; death losses, culling due to standard problems, and the maturation of the surviving and remaining animals, reaching the mature cow stage. The mature cow stage is assumed to be reached when the animals freshen for the second time, at approximately the thirty-seventh month. Purchases of young cows are permitted to occur in some of the simulations of the model. Purchases occur when there are fewer milkers than the number of desired milkers.

6.6 Cows

This is the final stage for milking animals on the dairy farm. An animal that has reached this stage is producing an acceptable quantity of milk and would generally not be culled until it has begun to pass its peak in milk output. The exact age at which this decline in output begins varies from animal to animal, but on average the acceptable milking animal is culled from a Michigan

herd at the age of sixty months¹². This rule of thumb is used for most simulations of this model, although the effects of lengthening the average life of the milk cow are explored in some simulations.

6.7 Desired Milkers

The operational goal of this subsystem is represented by the variable, Desired Milkers. This variable's specification depends on the type of behavior and causality actually occurring on the farm. Two specifications are used to examine the consequences of different types of behavior and feedback loops.

The first specification involves an exogenous determination of the value of the variable, implying that the farmer reacts to information other than the performance of the herd management sector in setting the operational goal. The exogenous specification can be changed in the midst of a simulation, as in a scenario where the farmer is assumed to desire a rapid expansion of the operation from one quantity of milkers to another. The second specification involves an exogenous component, as in the scenario given above, but also links feedback on the ability of the operation to meet the desired milker goal relative to the actual size of the goal. Figure 6.1 presents a causal loop diagram of the operation and emphasizes the potential importance of the presence or lack

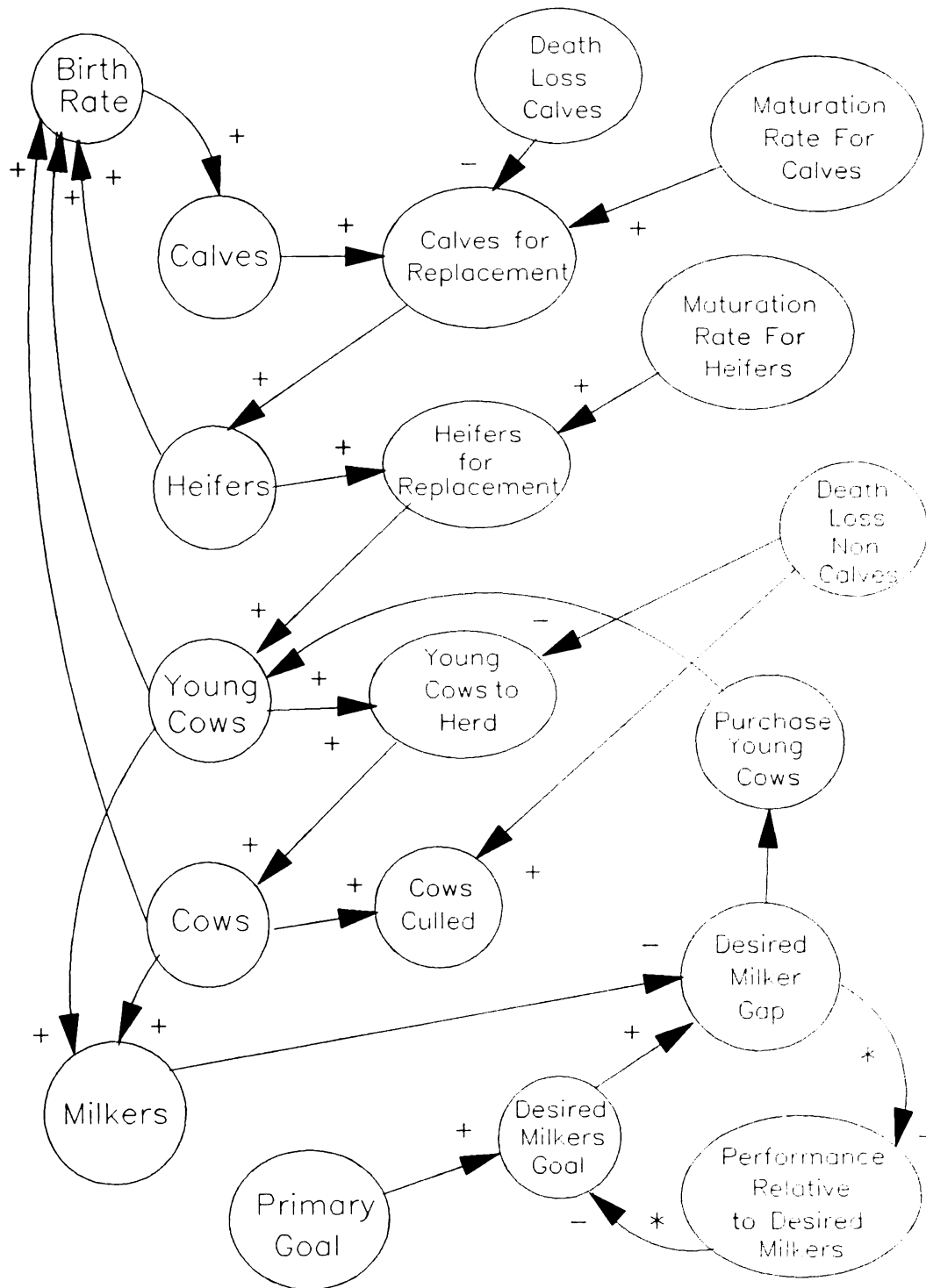


Figure 6.1: Partial Causal Loop Diagram of Herd Submodel; With and Without an Endogenous Desired Milker Goal

of such feedback.

As shown in the diagram, the size of the discrepancy between the actual number of milkers and the desired number is the Desired Milker Gap. First, assume that the loop connecting this gap to the Desired Milker goal is not present (the two arrows marked with a "*"), so that the goal is determined exogenously. In this case, if the number of Milkers falls short of the goal, purchases of young animals will occur, tending to bring the system back to an equilibrium as Milkers approaches and finally meets the Desired Milker goal. The behavior of the system given this type of structure is examined in the first set of simulations, in Chapter Seven.

Now assume that the link between the gap in the number of Milkers (Performance Relative to Desired Milkers) and the Desired Milker goal is present, thereby making this variable a function of exogenous and endogenous influences. The hypothesis is that the response of many farmers to not being able to meet their Desired Milker goal will lead to an increase in the size of the goal, perhaps thinking that if they have more milkers and therefore more births the system will be better able to produce replacements and maintain the desired number of milkers. Such behavior would be similar to the reaction of some operators to poor profits where the response is often to increase the size of the operation rather than improve the quality of

management¹³ [29]. As the Desired Milker goal goes up so will the purchases of young milkers, thereby increasing the number of milkers, but also the number of Cows Culled. The net result of endogenizing such behavior is examined in another set of simulations, below.

6.8 Cash Flow

The decision to expand the herd, even if only marginally, may be constrained in the short-run in some cases by the availability of cash. In the model of the entire herd, described in Chapter Four, cash flow was seen principally as a means to monitor performance relative to the primary strategic goal of the operation. The assumption was made in the entire herd model that cash would never be a constraint on the decision to marginally expand the herd. This assumption was made because of the historical ability of dairy farmers to obtain cash - primarily due to their monthly source of income and the willingness of creditors to lend short-term funds. Although there are times when these funds would not be available, this problem is not considered serious enough to warrant its inclusion in this herd management model.

6.9 Detailed Description of the Herd Management Sub-Model

The following is a list of the equations in the subsystem, organized around the major state variables in the age group. Text follows most equations giving a verbal explanation of the reasoning used for equation construction. Appendix Two contains a system dynamics diagram of the herd management simulation model and may be of help in analysis of the structural logic of the model. A list of all of the equations in STELLA format can also be found there as well. Appendix One contains a brief review of the notation used in both the system dynamics equations and flow diagrams.

(1) Calves

```
(1.1)      L   Calves.K = Calves.J + DT * (Calves In.JK -
              Calves Out.JK)
              (calves)
```

```
(1.2)      R      Calves In.KL = Birth Rate * Cows.K + (Young
                  Cows To Herd.KL + Heifers For Replacement.KL)
                  (calves per month)
```

```
(1.3)      C      Birth Rate = .0769
                        (fraction per cow per month)
```

The birth rate is essentially a function of the number of animals mature enough to bear young and the rate at which conception occurs. A good rule of thumb is that a cow will give birth once every thirteen months. This basic length of time will decrease or increase, depending on the specific birth management capacities of the farmer, but as a general guideline, thirteen months seems reasonable. For

this reason, the birth rate is simply $1/13$ times the number of cows plus the number of heifers and young cows ready to freshen. Heifers become young cows when they freshen for the first time and young cows become cows when they freshen for the second time. Counting the number of freshening heifers and young cows is therefore the same as counting the number of calves born (these variables are defined in detail below). Some seasonality should be expected in the birth rate, but is not considered significant enough for the purposes of this model to be incorporated.

$$(1.4) \quad R \quad \text{Calves Out.KL} = \text{Calves.K} * (\text{Death Loss Calves} + \text{Maturation Rate Calves})$$

(calves per month)

The number of young calves leaving this stage is a simple function of the number of calves in the state variable times the sum of rates at which calves die and mature. Some of these surviving and maturing animals are bull calves, and are sold (see below), while the surviving and maturing females are either sold or are entered into the heifer stage of the herd (see below).

$$(1.5) \quad C \quad \text{Death Loss Calves} = .14 \text{ per four months or } .035$$

(fraction per month)

The rate of calf death loss will vary from farm to farm depending on the conditions and the management skills of the farmer [12], but the generally used rule of thumb is 14 to

15 % of all calves will die due to disease by the time they reach four months of age¹⁴. If a 14% loss is assumed, then each month 3.5% of the animals die.

(1.6) C Maturation Rate Calves - .25
(fraction per month)

The calf maturation rate is simply one every four months.

(1.7) A Calves Needed.K - Desired Milkers.K * Steady
 State Removal Rate
 (calves per month)

This is the number of heifer calves needed to maintain the desired herd size assuming that no purchases will be made of ready to freshen or freshened animals. It is equal to the steady state removal rate of mature animals from the herd times the number of desired milkers.

(1.8) C Steady State Removal Rate = (Death Loss Cows
+ Cull Rate Standard Cows + (Expansion and
Expected Death Loss Factor)
(fraction per month)

(1.9) C Expansion and Death Loss Factor = .017
(fraction per month)

1.8 is calculated by the standard cull rate of milking animals, plus 5% for potential herd expansion and 15 % for death loss between calf to milker on an annual basis;
.20/12 - monthly rate.

(1.10) A Calves For Replacement.K - Calves Out.JK *
 (1 - Death Loss Calves)
 (calves per month)

Of the calves moving out of the Calf state, some are lost due to death. This equation defines the proportion available for entering the next stage of maturation.

(1.11) A Sale Bull Calves.K - Calves For Replacement.K
 * Bull Calf Rate
 (male calves per month)

(1.12) C Bull Calf Rate = .50
 (fraction males per calf per month)

The sale of bull calves is equal to one half of the surviving calves. All bull calves are assumed to be sold.

(1.13) A Sale Heifer Calves.K -
 If Desired Milker Gap.K > 0
 Then 0
 Else If Calves Needed.K > Calves For
 Replacement.K - Sale Bull Calves.K
 Then 0
 Else (Calves For Replacement.K - Sale Bull
 Calves.K) - Calves Needed.K
 (calves per month)

The sale of heifer calves is more complicated than the sale of bull calves, since most of the animals needed to maintain the desired milking herd size are generated from within the farm. The number of heifer calves sold is equal to the surviving and maturing animals minus the number of bull calves sold and minus the number of calves needed to enter the herd in order to maintain a steady state milking herd size (neither growing or declining). The fact is that

there will rarely, if ever, be any excess calves if there is a desire to expand the herd. For this reason, if the Desired Milker Gap is greater than zero, then no heifer calves are sold. Also, if there are fewer heifer calves available than those needed then none will be sold.

Desired Milkers is either an exogenous or endogenous variable, depending on the behavior being analyzed. Assumptions can be made about the farmer's desired size of operation, and given this goal, the performance of the rest of the model can be observed. Endogenous effects are limited to reactions to the degree of attainment of the desired level of milkers, which is assumed to potentially lead to the desire to further changes in the herd size. Consult Chapter Seven for details on how this variable is treated in various simulations.

(2) Heifers

$$(2.1) \quad L \quad \text{Heifers.K} = \text{Heifers.J} + \text{DT} * (\text{Heifers In.JK} - \text{Heifers Out.JK})$$

(heifers)

The stock of heifers, from age 5 to 27 months, at which point they freshen.

$$(2.2) \quad R \quad \text{Heifers In.KL} = \text{Young Heifers Available.K}$$

(heifers per month)

$$(2.3) \quad A \quad \text{Young Heifers Available.K} = \text{Calves For Replacement.K} - \text{Sale Bull Calves.K} - \text{Sale Heifer Calves.K}$$

(heifers per month)

The rate at which heifers accumulate; equal to the number of maturing and surviving calves minus the number of calves sold plus the number of young heifers purchased (if any).

$$(2.4) \quad R \quad \text{Heifers Out.KL} = \text{Heifers.K} * (\text{Death Loss Heifers} + \text{Maturation Rate Heifers})$$

(heifers per month)

The rate at which heifers decline; equal to the number of heifers times the sum of the rate at which they mature and the rate of death loss.

$$(2.5) \quad C \quad \text{Maturation Rate Heifers} = .0435$$

(fraction per month)

The maturation rate for heifers. They remain in this state for 23 months, or one heifer leaves every 23 months, or .0435.

$$(2.6) \quad C \quad \text{Death Loss Heifers} = .0058$$

(fraction per month)

Heifers die at roughly 7% per year, or .0058 of the animals per month¹⁵.

$$(2.7) \quad A \quad \text{Heifers For Replacement.K} = \text{Heifers Out.KL} * (1 - \text{Death Loss})$$

(heifers per month)

The number of heifers moving out is actually the survivors. The death loss is subtracted from one to determine the proportion of heifers moving out that are surviving.

(3) Young Cows

$$(3.1) \quad L \quad \text{Young Cows.K} = \text{Young Cows.J} + \text{DT} * (\text{Young Cows In.JK} - \text{Young Cows Culled. JK} - \text{Young Cows To Herd.JK})$$

(young cows)

The number of young cows (first freshened animals who are giving milk) is a function of many variables, one of which is the purchases of young cows (a state variable treated separately, below). The milking herd is divided into two categories to permit the model to more easily account for the different management decisions made by the farmer relative to the age of the milking animal.

One of the primary herd management assumptions is that cows are generally culled once they reach the age of 60 months, so that animals between their first freshening and 60 months are the milk producers. The consequences of extending the life span beyond 60 months is investigated in some simulations of the model, but the value of 60 is assumed to be the baseline or equilibrium value. If there is a desire to expand the herd, then the farmer is assumed to prefer to maintain the SOP of culling older animals and expand by either retaining more young cows or purchasing young cows. In the case of there being a desire to contract

the milking herd size, the farmer is assumed to prefer to cull more older (and presumably poorer milk producing) cows and maintain a constant rate of young animal retention. Of course there will be young cows who are terrible producers and some 60 month cows who are tremendous producers and the farmer would be expected to cull differently under these conditions, but such quality details are beyond the scope of this research. In general, the assumptions made about the farmers decisions seem to be the most likely to contribute to an increase of herd average rate of milk per cow¹⁶.

Another reason for separating the two ages of animals relates to the retention decision of young animals itself. This decision is one of the most crucial for herd improvement. It is generally assumed to be nearly impossible to decide on the future quality (breeding and milking characteristics) of a heifer. It is necessary to wait until a heifer has carried for her first term and/or begun to produce milk that a determination can be made of the animals quality and the likelihood of her retention in the milking herd¹⁷.

Although in this model every milking animal is given the same breeding and milk producing characteristics, allowance is made for some young animals to be of inferior quality (see Cull Rate Standard Young Cow below). The separation of cows from young cows and the presence of the

quality variable will permit the introduction of a stochastic quality element if it is deemed necessary in future research (a RANDOM designation is available in STELLA).

$$(3.2) \quad R \quad \text{Young Cows In.KL} - \text{Heifers For Replacement} + \text{Young Cows Arriving.KL} \\ \text{(young cows per month)}$$

The rate at which young cows are accumulating; equal to the number of maturing heifers and the purchases of young cows. Heifers For Replacement is defined above in eq. (2.8).

Purchasing younger animals permits the farmer to continue to use the SOP governing the culling of mature milkers.

$$(3.3) \quad L \quad \text{Young Cow Orders.K} - \text{Young Cows Orders.J} + \text{DT} * (\text{Young Cow Orders In.JK} - \text{Young Cow Arrivals.JK}) \\ \text{(young cows)}$$

The state variable defining the quantity of young animals the farmer is in the process of purchasing. The assumption is that it takes time to perceive the need to purchase the animals and it takes time for the animals on order to arrive.

$$(3.3a) \quad R \quad \text{Young Cow Orders In.KL} - \text{Young Cow Purchases Needed.K} / \text{Time to Perceive Purchase Need} \\ \text{(young cows per month)}$$

The Base Value is generally set at 45 animals, an arbitrary level. The average size of the gap, either positive or negative, represents the performance of the herd relative to the goal and this measure of performance is used to adjust the goal up or down.

$$(3.3f) \quad L \quad \text{Desired Milker Gap Average.K} = \text{Desired Milker Gap Average.J} + DT * (\text{Desired Milker Avg Gap In.KL})$$

(milkers)

This is an averaging process commonly used in system dynamics that involves a goal-gap formulation [26, p271-272, & 308-310]. The current value for the Desired Milker Gap is being averaged into the performance measure, Desired Milker Gap Average.

$$(3.3g) \quad R \quad \text{Desired Milker Avg Gap In.KL} = \text{Desired Milker Gap Gap.K} / \text{Time to Average Desired}$$

(milkers per month)

$$(3.3h) \quad A \quad \text{Desired Milker Gap Gap.K} = \text{Desired Milker Gap.K} - \text{Desired Milker Gap Avg.K}$$

(milkers)

$$(3.3i) \quad C \quad \text{Time to Average Desired Gap} = 6$$

(months)

The equations 3.3g - 3.3i are a fairly standard treatment of a goal gap averaging process. The reader who finds this formulation confusing and would like to know how it works is advised to consult the textbook cited above.

$$(3.3j) \quad R \quad \text{Young Cow Arrivals.KL} = \text{Young Cows Orders.K} / \text{Time to Purchase Young Cows}$$

(young cows per month)

The rate at which young cows being purchased arrive at the farm is equal to the current number of animals on order divided by the time it takes for the order to be filled. The time constant represents the time it takes to arrange for the purchase and delivery of the animal.

$$(3.3k) \quad C \quad \text{Time to Purchase Young Cows} = 2 \text{ (months)}$$

$$(3.3l) \quad A \quad \text{Milkers.K} = \text{Young Cows.K} + \text{Cows.K} \text{ (milkers)}$$

$$(3.4) \quad R \quad \text{Young Cows Culled.KL} = \text{Young Cows.K} * (\text{Death Loss Young Cows} + \text{Maturation Rate Young Cows}) + \text{Cull Rate Standard Young Cows} \text{ (young cows per month)}$$

There are three reasons for the removal of young cows from the herd; losses due to death, or animals that need to be removed from the herd because they are poor milk producers or poor reproducers. The last two reasons are represented by the last variable in the equation.

$$(3.5) \quad C \quad \text{Death Loss Young Cows} = .0058 \text{ (fraction per month)} \\ \text{(Seven \% a year)}$$

$$(3.6) \quad C \quad \text{Maturation Rate Young Cows} = .09834 \text{ (fraction per month)}$$

The assumption is that these animals will be culled only after they have completed their first lactation, even though they are not average producers. If it takes ten months to complete a lactation then approximately 9.8 % of the animals that are going to be

culled are removed each month.

(3.7) C Cull Rate Standard Young Cows - .0042
 (fraction cows per month)

This cull rate reflects the assumption that a certain portion of the young cows will need to be culled due to unavoidable problems with either breeding or producing milk (or just poor milk production). This portion is likely partly endogenous to the system (a function of the herd improvement practices) as well as partly stochastic and therefore exogenous to the management system. For the purposes of this research a single, constant portion set arbitrarily at 5 percent per year is adopted. The Dairy Herd Improvement Association publishes some Michigan data about culling in DHIA herds for these reasons but it was not possible to distill a single number from the data. The 5 percent I selected has no empirical or expert justification at all and should be more precisely determined at some time. (It is unlikely that the culling for this reason is much larger than 5%, for if it was it would seem to be an important source of loss and would therefore have more concrete data published about it. If there is error in this assumed value of 5 percent, it is likely an overestimation of the losses due to these problems so that the ability of the system to produce retainable animals is not over exaggerated. Yet it is possible that these losses are more significant than what has been assumed.)

$$(3.8) \quad A \quad \text{Sale Young Cows.K} = \text{Young Cows Culled.KL} * (1 - \text{Death Loss Young Cows})$$

(young cows per month)

Only the proportion of animals removed from the herd for reasons other than death loss can be sold (for butchering or as milk producing animals).

$$(3.9) \quad R \quad \text{Young Cows To Herd.KL} = \text{Young Cows.K} * \text{Maturation Rate Young Cows}$$

(young cows per month)

The assumption is that a young cow becomes a mature cow when it freshens for the second time, which is essentially the end of the first, which occurs on average ten months after the last freshening (assuming a nine month gestation).

$$(3.10) \quad C \quad \text{Maturation Rate Young Cows} = .09834$$

(fraction per month)

(4) Cows

$$(4.1) \quad L \quad \text{Cows.K} = \text{Cows.J} + \text{DT} * (\text{Young Cows To Herd.JK} - \text{Cows Out.JK})$$

(cows)

Animals enter from the young cow state and exit according to the standard cull rate of 60 month life-cycle, with provisions for increasing the cull rate to accommodate a desire for rapid contraction of the milking herd.

(4.2) R Young Cows To Herd.KL = (see eq. 3.9)

(4.3) R Cows Out.KL = Cows.K * (Death Loss Cows +
Cull Rate Standard Cows) + Cull Rate Variable
Cows.K
(cows per month)

The rate at which cows disappear from the herd. The variable is a function of the standard rate of culling, death loss, and a variable cull rate depending on the desired change in milking herd size change (if any).

(4.4) C Death Loss Cows = .0058
(fraction per month)

This variable takes the same value as that for young cows, .07 a year or .0058 a month.

A4.5 C Cull Rate Standard Cows = .0455
(fraction per month)

The cull rate based on the age of the animal, where any animal reaching the age of 60 months is removed from the herd. The SOP here is that this policy is maintained to attain the best average milk producing herd. The time spent in this state is 22 months (from 38 to 60), so that the variable is equal to $1/22 = .0455$.

(4.6) A Cull Rate Variable Cows.K =
If Desired Milker Gap.K < 0
Then - Desired Milker Gap.K
Else 0
(cows per month)

The Desired Milker Gap is a measure of the difference between the number of milking animals desired and the number actually currently on hand. If there are not enough milkers on hand (Desired Milker Gap > 0) then purchases of young cows will occur (see above, eq. (3.3)) and there will be no change in the mature cow cull rate. (This is not strictly true for all sensitivity analysis simulations. Some analysis is done on the effects of retaining mature animals for longer than 60 months. See Chapter Seven for more detail.) If there are more milkers on hand than desired, then the excess milkers will be removed from the stock of mature cows, the assumption being that on average the younger animals will have better characteristics.

$$(4.7) \quad A \quad \text{Sale Cull Cows.K} = \text{Cows Out.KL} * (1 - \text{Death Loss Cows})$$

(cows per month)

The proportion of animals not lost due to death are sold.

6.10 Summary

Five major components make up the herd management model. Four of the components revolve around the separation of the herd according to ages representing different management problems and needs. These four are calves (0-4 months), heifers (5-27 months), young cows (28-38 months), and cows (39-60 months). The fifth component is the

variable defining the major impetus for change in the system, the desired number of milkers. Desired Milkers is specified differently according to the scenario being conducted.

Four different sets of simulations of this model are performed and presented in the following chapter.

CHAPTER SEVEN

SIMULATION OF THE HERD MANAGEMENT MODEL

7.1 Introduction

The principle reasons for simulating a system dynamics model is to explore the properties of the system in question. This exploration primarily takes the form of examining the system's sensitivity to specific variables and structural loops within the system. Before this examination can take place, validation of the model must be undertaken to determine if it is suitable for sensitivity analysis. Validation involves the question, does the model represent a real system? This can be answered by comparing simulation results to the expectations of persons with relevant experience, or comparing the results to actual data, or both. The goal in constructing the herd management model was not so much to create a "real system" as it was to answer the questions from the introduction to Chapter Six. These questions are:

- 1) Can STELLA be used to model a specific part of the dairy operation?
- 2) Can this model rely on the use of SOP's to guide the operation?

If STELLA is capable of translating assumptions concerning SOP's and the way they are organized in specific operations into a simulation model that gives reasonable results, then it would be possible to answer yes to both of these questions. It is not necessary for the model to give

completely expected results; unforeseen but reasonable results should be expected to occur given that the simulation technique permits extremely complex interactions between relatively straightforward SOP's.

The validity of the herd management model is therefore a question of whether or not the simulation results seem reasonable given the design of the model. This is in contrast to the normally used meaning of validity presented above. Given that the herd management model is intended to answer less rigorous questions than a model which undeniably represents a real system, a less rigorous criterion of validity should be appropriate. Although a significant attempt has been made in this modeling effort to design a system of realistic SOP's, it is left to future research to more conclusively investigate whether or not we can develop assumptions concerning SOP's and their organization that do in fact precisely represent a real system.

The test of validity used here is essentially that used by Balderston and Hoggatt, which they called the criterion of model viability (see Chapter Five, pages 55-59). This criterion is nothing more than; can the model be simulated and give results consistent with what one would expect given the design and specification of the model? The validity of the herd management model, as judged by the simulation results, is therefore dependent in part on the

congruence between what we would expect, given the assumptions concerning the relationships among the important management procedures, and the actual simulation results.

The test of validity is really a pragmatic test of the reasonableness of the assumptions that make up the model as well as the reasonableness of the results, both of which cannot be judged independently of the intended use of the model. The bulk of the argument of the model's validity really centers on informed debate about the quality of the assumed SOP's and the structure uniting the SOP's into one system.

Although a more clear specification of performance criteria would be desirable, for the purposes of judging the herd management model, it is assumed that congruence will be demonstrated if the results indicate that the births and deaths of animals are occurring and that there are animals being culled and sold. No comparison is made to data from actual farms, which is a shortcoming of the analysis, but if the goal is to demonstrate the congruence between assumptions and results, the comparison of results to actual data takes on less significance.

The first set of simulation runs below, set I, are runs of the basic model with marginal changes in some principle parameters. The simulation results are judged with the viability-congruence criterion in mind.

The third question asked in the introduction to Chapter Six was:

3) Could a model oriented towards a specific problem constructed in STELLA be of possible use to agricultural economists?

A relatively objective test of whether STELLA could be a valuable tool would be for agricultural economists to pose actual problems to which STELLA could be applied. If satisfactory answers were found, then with a certain degree of confidence the answer would be yes.

The test used here for determining STELLA's problem solving capacity is more limited and therefore less conclusive than the above proposed relatively objective test. Hypothetical herd management practices relative to the problem of obtaining and maintaining a desired milking herd size are postulated as a proxy for the questions of agricultural economists. These questions are asked in Runs II-IV within the context of sensitivity analysis, meaning that the runs make changes in certain important variables and loops to determine their importance to the herd management system. The results of these runs are judged relative to the question of STELLA's usefulness to agricultural economists in the conclusion to this chapter.

The simulation runs detailed below fall into four categories. The results from each run within a category are summarized in tables to be found in the text. The categories of runs are: I, no purchases of replacement

stock, a condition which allows us to examine the model's viability and basic properties; II, constant purchases SOP; III, variable purchases SOP; and IV, linking Desired Milkers to performance (incorporating feedback directing the entire subsystem).

7.2 The Herd Dynamics Without Purchases of Replacements

The underlying structure and properties of the model can be explored by simulating it without any purchases of replacement stock. Under these conditions, the herd is forced to react as if it represented the dairy cows in a completely closed system, like a country with no imports of live animals. The simulation results reveal the various strong and weak effects of the death and cull rates on the herd as a whole. The results also demonstrate the need for purchasing replacement animals if the individual farmer either starts with an inadequate level of replacement stock or is constrained to an inadequate level by housing or management limitations.

7.2.1 Run IA; Baseline For No Purchases

A simulation model of the type created for the dairy herd tends to reach an equilibrium or steady state if there are no unstable cyclic reactions in the model or external shocks. The steady state reflects a balancing between the number of animals present in each of the states, Calves,

Heifers, Young Cows and Cows, and the losses of animals from each of these states.

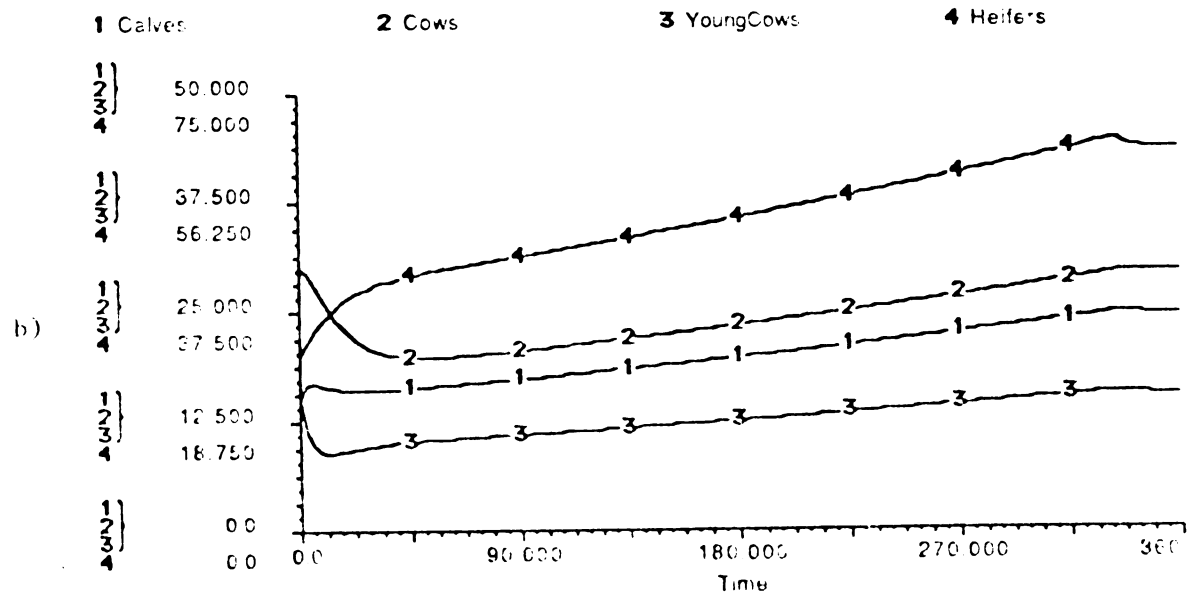
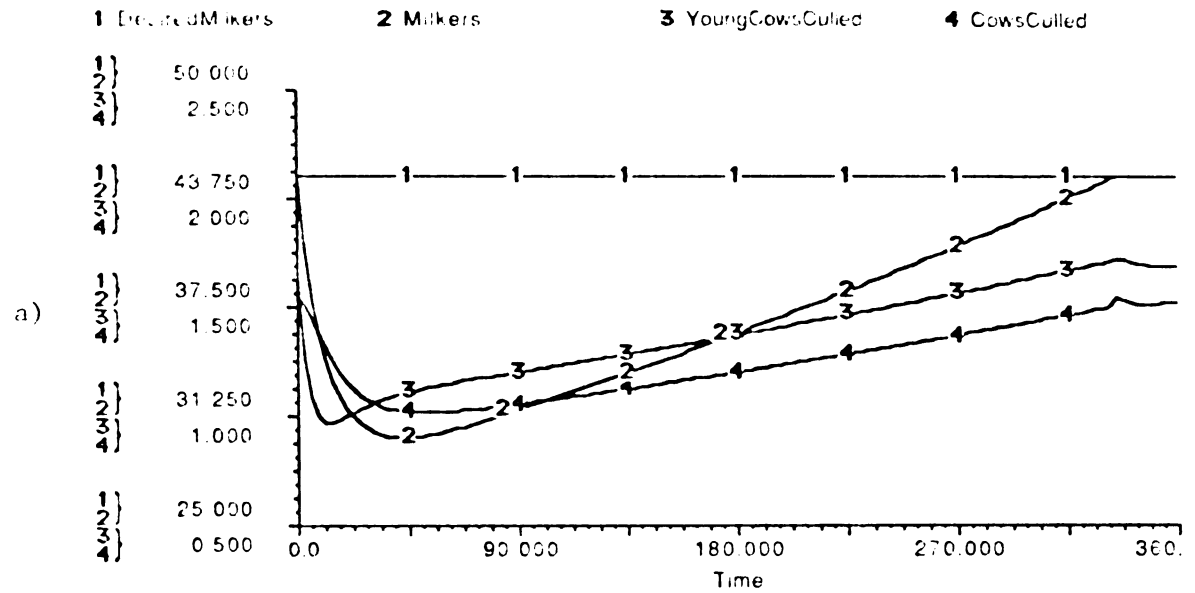
This baseline or steady state is established simply by simulating the model and noting the final values. Aside from the specified death losses and cull rates given in Chapter Six's detailed description above, the starting values of each of the states need to be established before the run. For simple expositional purposes, the milking herd is assumed to be 45 animals; 30 Cows and 15 Young Cows. The Calves are started at 15 and Heifers at 30. The values and other beginning conditions of this baseline run with no purchases is presented in Table 7.1a. The graphical results from this run are in Figure 7.1a-b.

Table 7.1a: No Purchases, Baseline, Run IA

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milker goal: Constant, 45 Milkers

Initial Value of State Variable	Variable	Final Value of State Variable
15	Calves	25
30	Heifers	65
15	Young Cows	15
30	Cows	30

Time to Steady State: 334 months



Figures 7.1a-b: Baseline For No Purchases, Run 1A.

The time paths of four variables are depicted in Figure 7.1a, Desired Milkers, Milkers (the sum of cows and young cows) and the cull rates for Young Cows and Cows. The goal, Desired Milkers, is assumed to be a constant 45 milkers. The number of Milkers falls drastically at the start of the simulation to less than 30 animals and eventually reaches the goal after approximately 334 months.

The reason for this large decrease in Milkers and the long lag until reaching the goal is the inadequate level of replacement stock (Heifers and Calves). Although the Young Cows Culled and Cows Culled fall as the milking herd falls, the effect of the removals of Milkers overwhelms the capacity of the system to provide replacements. Eventually, at approximately month 45 the culling of milkers has dropped enough to permit the gradually expanding stock of replacements to rebuild the milking herd. The increase in Calves and Heifers and the associated increase in Cows and Young Cows starting in month 45 can be seen in Figure 7.1b.

The entire dairy herd stabilizes eventually at 25 calves, 65 heifers, 15 Young Cows and 30 Cows.

7.2.2 Run IB; Altering Calf Death Losses

One area of intervention in this model of the dairy herd is at the point of calf death loss. The assumed value of 14 percent per year is an average for Michigan DHIA herds although some farms have much lower rates of loss.

This run uses the same starting point as above except for decreasing the Death Loss Calves from 14 percent to 7 percent per year. Starting and ending information is in Table 7.1b, and the graphical results are presented in Figures 7.2a-b.

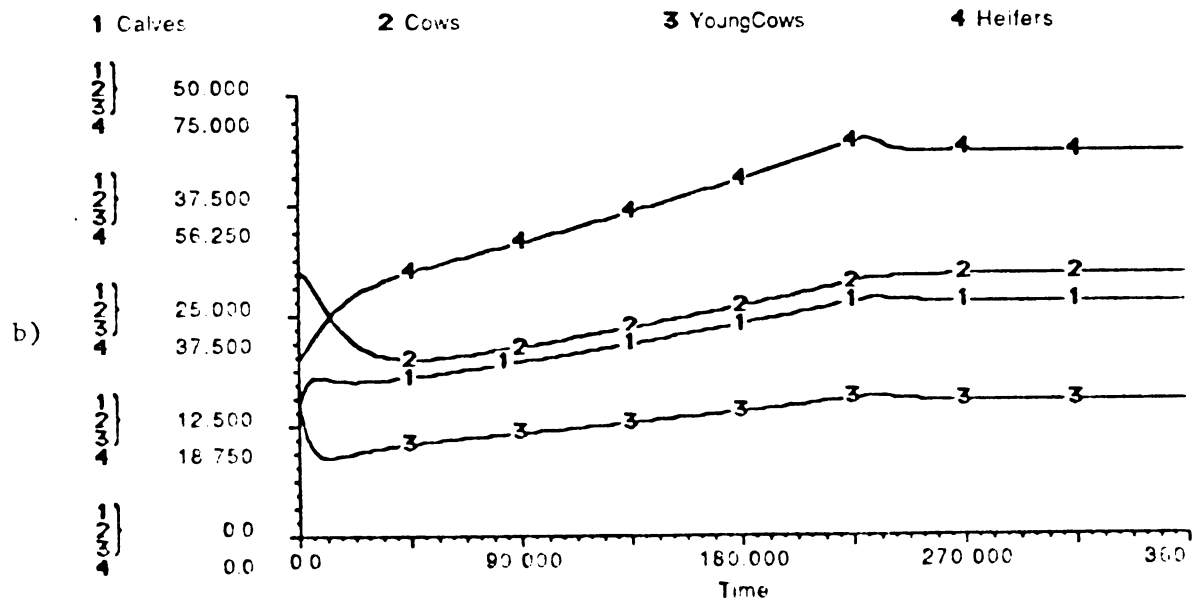
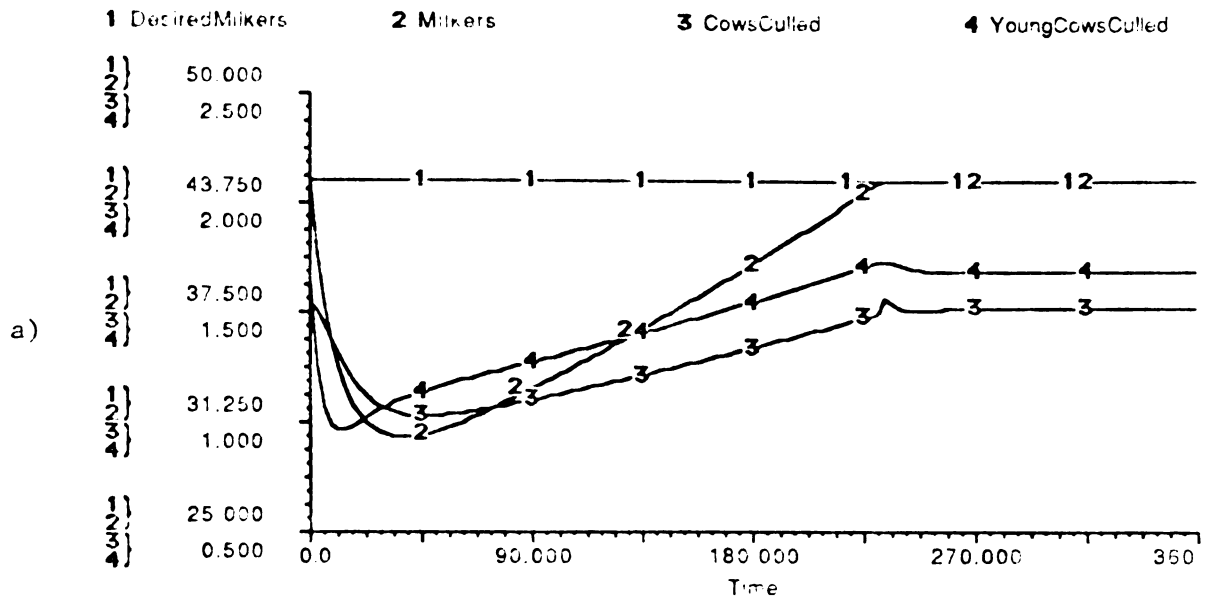
Table 7.1b: Altering Calf Death Losses, Run IB

-
- Cull Rates: Standard
 - Death Losses: Altered, Death Loss Calves = 7% per year
 - Desired Milker goal: Constant, 45 Milkers

Initial Value of State Variable	Variable	Final Value of State Variable
15	Calves	27
30	Heifers	65
15	Young Cows	15
30	Cows	30

Time to Steady State: 234 months

The variables graphed in this run are identical with those in IA. Between the two sets of runs, the time paths of the variables are very similar, except that it takes much less time for this herd to reach steady state: while the baseline herd in run IA took 334 months to reach steady state, reducing the death losses to calves allowed the herd to reach the goal in 234 months. The values for the state variables in steady state in this run are identical with those from the Run IA, except for the increase in two calves when death losses are reduced.



Figures 7.2a-b: Baseline with Calf Death Loss Altered, Run IB.

7.2.3 Run IC; Altering the Cull Rate Standard For Cows

The assumption that on average Cows are culled at the age of 60 months is a reflection of the pattern of milk output for the dairy animals. In other words, the assumption is that on average, milking animals are sufficiently past their peak at 60 months to warrant their removal from the herd. What if this point were not reached until the age of 72 months? It seems likely that increasing the average age of the Cow should have large effects on the dairy herd.

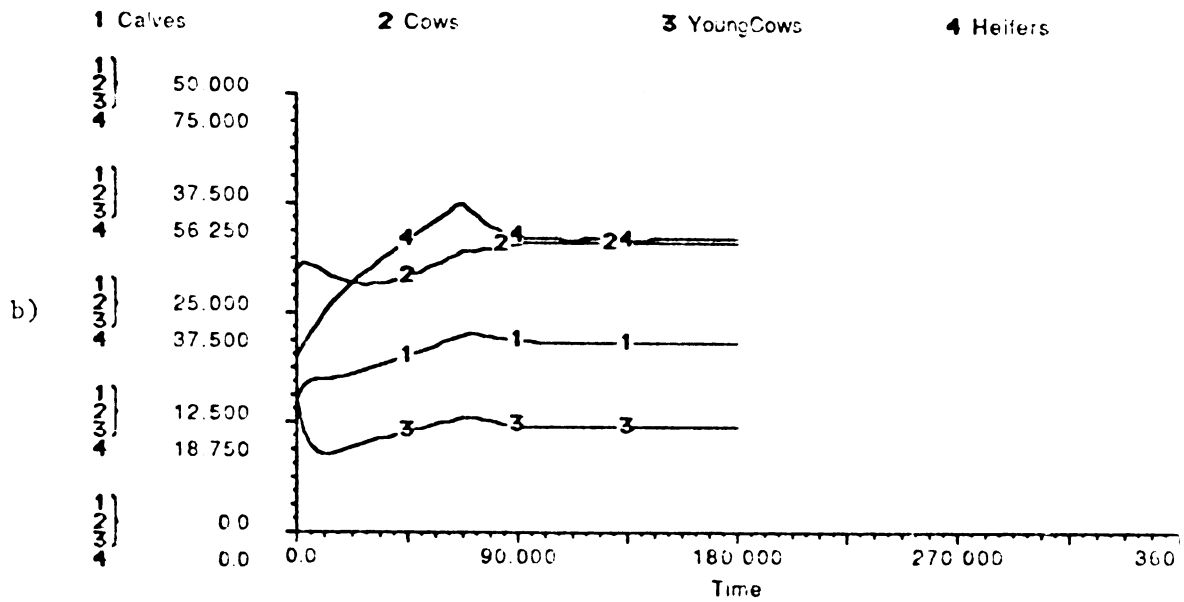
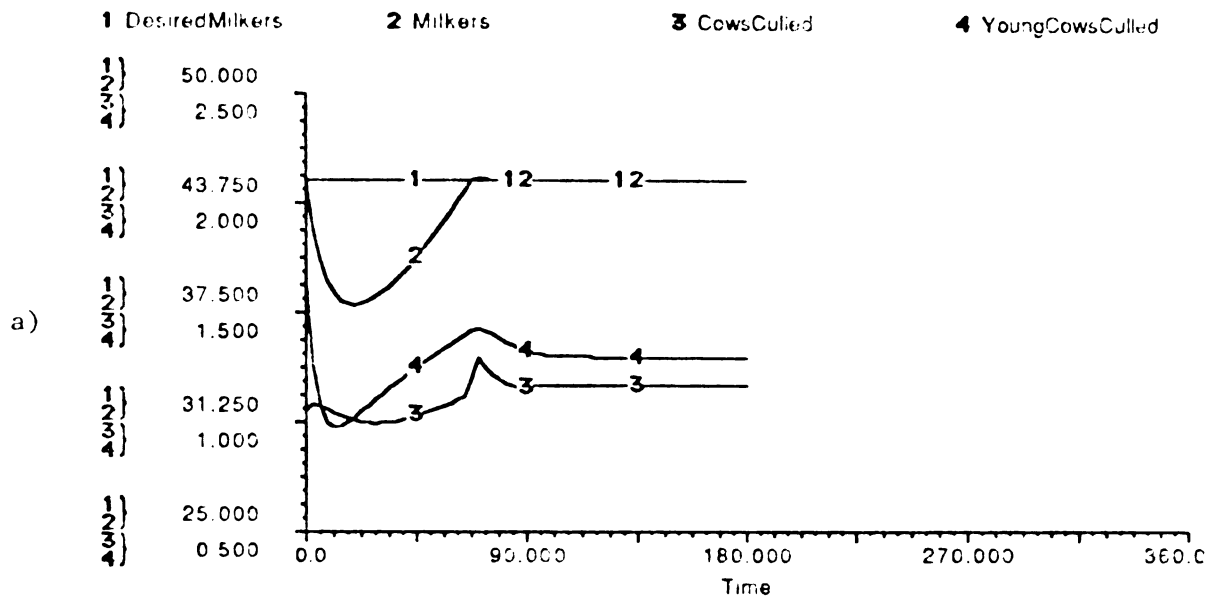
Table 7.1c summarizes the starting and ending conditions for this run. The baseline conditions from Run IA are used, except for increasing the average age of Cows to 72 months.

Table 7.1c: Altering Cull Rate Standard Cows, Run IC

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milker goal: Constant, 45 Milkers

Initial Value of State Variable	Variable	Final Value of State Variable
15	Calves	25
30	Heifers	50
15	Young Cows	12
30	Cows	33

Time to Steady State: 66 months



Figures 7.3a-b: Baseline With Cull Rate Standard for Cows Altered,
Run 1C.

The simulation results graphed in Figure 7.3 a and b show that both the time it takes to reach steady state and the time paths of the variables are significantly different than either IA or IB. The principle effect of the increased age is that there are more births of calves in the herd. The relatively rapid increase in Calves and Heifers (Figure 7.3b) feed more animals into the milking herd. By month 66, there are so many heifers that there is pressure on the milking herd to increase beyond the desired level. The sharp increase in Cows Culled (Figure 7.3a) in month 66 reflects the effect of the culling of these excess Cows. Within a few months the herd reaches it's steady state with the levels of animals in the various states different from those in either IA or IB (see Table 7.1c).

7.2.4 Discussion of Runs IB and IC

Either of these two changes in the baseline, reducing calf death losses or increasing the average age of Cows could be incorporated into the herd management model. In fact, the death losses could be made endogenous to the system, responding to a level of management expertise following some sort of learning curve. Or, average cow age at the time of culling could be a stochastic, normally distributed variable, moving randomly between 60 and 72 months, or any desired age. The zero point of the normal distribution could be altered over time to reflect the

changing genetic composition of the herd.

Although these modifications are possible, for expositional purposes in all of the following runs it is assumed that the values of cull rates and death losses are those used in IA. Still, the basic implication of all of these runs is the same; the farmer needs to either have sufficient levels of replacement stock or must be able to purchase animals if the Desired Milker goal is to be reached in fewer than five to thirty years.

7.2.5 Run ID; Adequate Stocks of Replacements

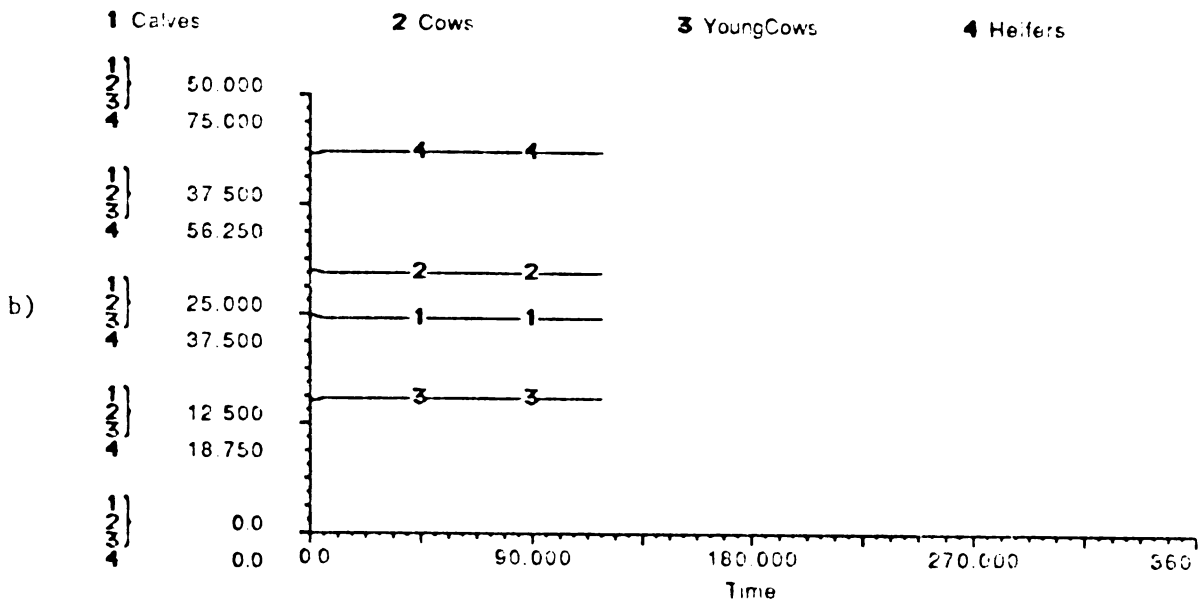
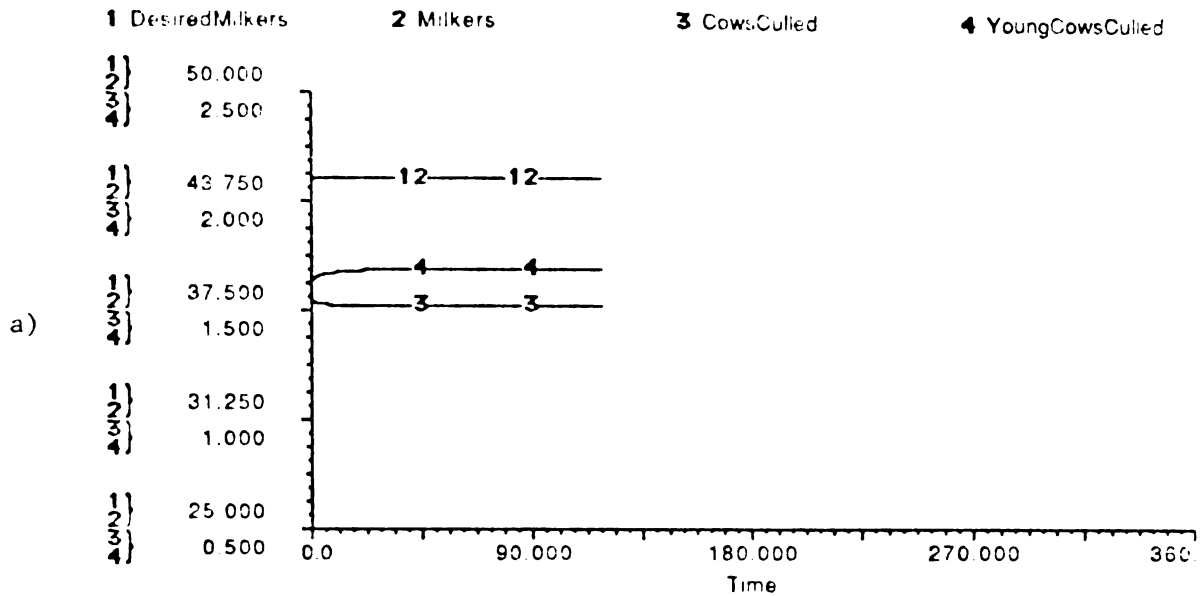
Starting the herd off with the steady state number of replacement animals causes the results you would expect; Milkers equals Desired Milkers from the start, with essentially no deviation from the initial condition. The results are summarized in Table 7.1d. Graphs of the results

Table 7.1d: Adequate Stocks of Replacements, Run ID

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milker goal: Constant, 45 Milkers

Initial Value of State Variable	Variable	Final Value of State Variable
25	Calves	25
65	Heifers	65
15	Young Cows	15
30	Cows	30

Time to Steady State: 0 months



Figures 7.4a-b: Baseline With Adequate Stocks of Replacements, Run ID.

are in Figures 7.4 a and b. The simulation is aborted after 100 months due to lack of interest in straight lines.

7.2.6 Model Viability and Validity

The herd management model performs well relative to the criteria of reasonableness of results and their congruence with the design of the model. Births, deaths, culling and sales all are occurring, and although the steady state levels of animals in the herd varied according to changes in fundamental parameters, the results are consistent with the assumptions of the run as well as the SOP's in the model. Lacking more formal criteria, the conclusion to be drawn is that the model is viable.

7.3 SOP on Constant Purchases of Replacements

Not all farmers will be able to raise the quantity of replacement stock demonstrated in Run ID that is needed to maintain the herd at the Desired Milker level. The constraints on animal housing, ration supplies, labor and management skills could limit the total number of replacements the farmer can maintain. In this set of runs, for expositional purposes the farm is assumed to be able to raise only as many Heifers as there are Milkers. Calves can only reach to two-thirds of the number of Milkers. Before examining a constant purchases SOP it will be helpful to demonstrate the effects of these constraints.

7.3.1 Run IIA, Constrained Stock, No Purchases

The constraints on the stock of replacement animals forces the farmer to purchase replacements if the Desired Milker goal is to be met. Figures 7.5 a and b present graphs of the results of a simulation with these conditions. The main features of the run are summarized in Table 7.2a.

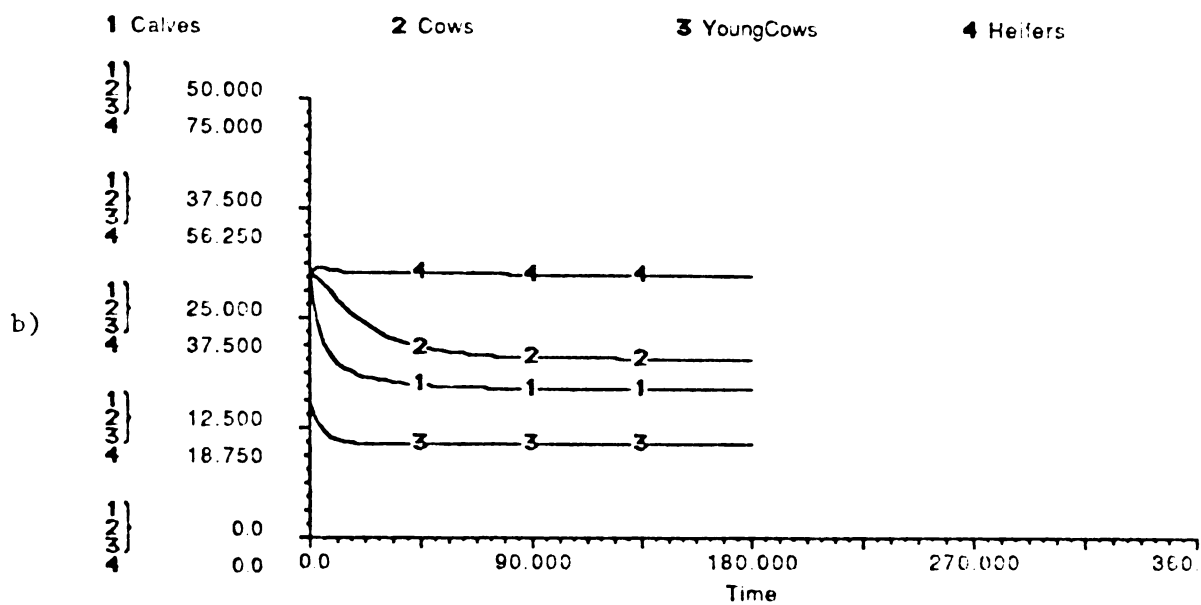
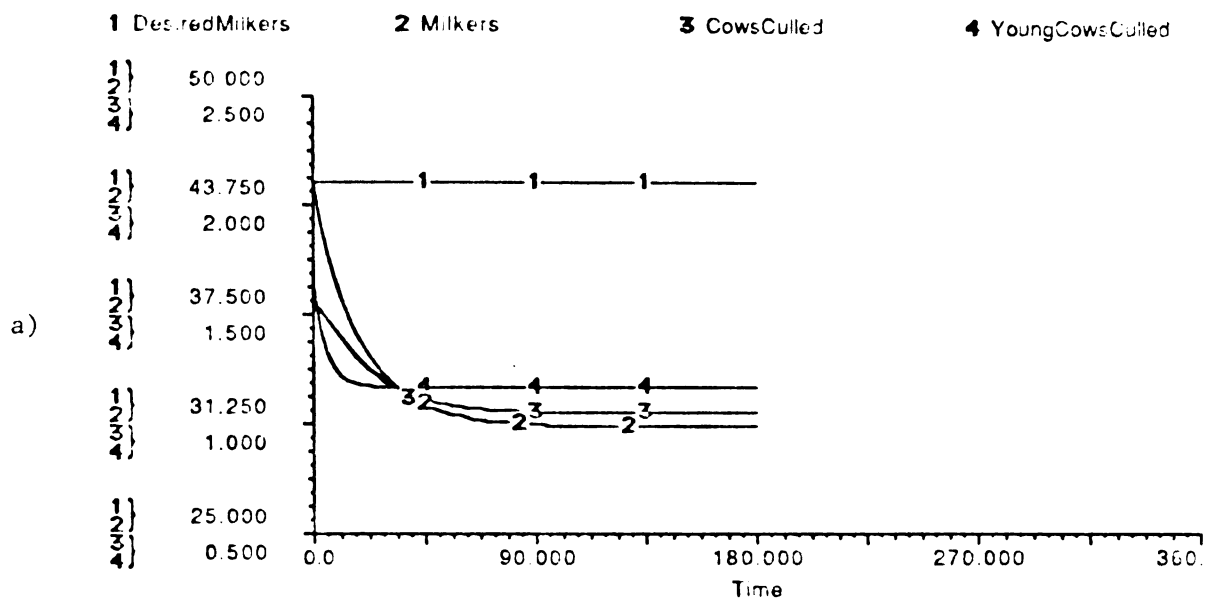
Table 7.2a: No Purchases and Constrained Stock, Run IIA

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milker goal: Constant, 45 Milkers

Initial Value of State Variable	Variable	Final Value of State Variable
25	Calves	17
45	Heifer	45
15	Young Cows	11
30	Cows	20

Time To Steady State: 80 Months

The removals of both Cows and Young Cows initially pulls the number of Milkers down as before in the runs in I. The difference is that Young Cows and Cows are never able to recover to Desired Milkers as any Heifers in excess of the 45 animal constraint must be removed from the herd. The dairy herd's steady state condition is only 31 Milkers, with 11 Young Cows and 20 Cows. There are fewer calves than



Figures 7.5a-b: No Purchases and Constrained Stock, Run IIA.

the 25 animal constraint because of the lack of animals giving birth.

7.3.2 Run IIB, Constant Purchases SOP

The farmer could have an SOP associated with the Desired Milker goal of 45 animals which dictates the purchase of two Young Cows every month. Such an SOP could be the result of the farmer's own experience or it could be learned from an experienced farmer. If a son takes over a dairy operation from his father, and if the father always purchased two animals a month then the son may very well do the same.

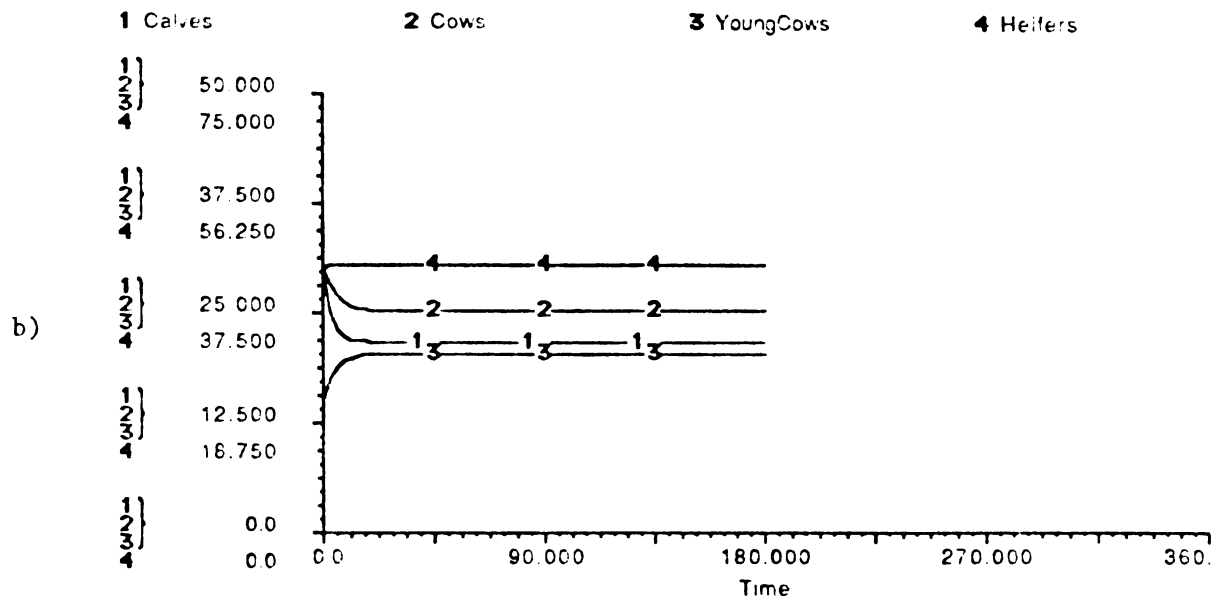
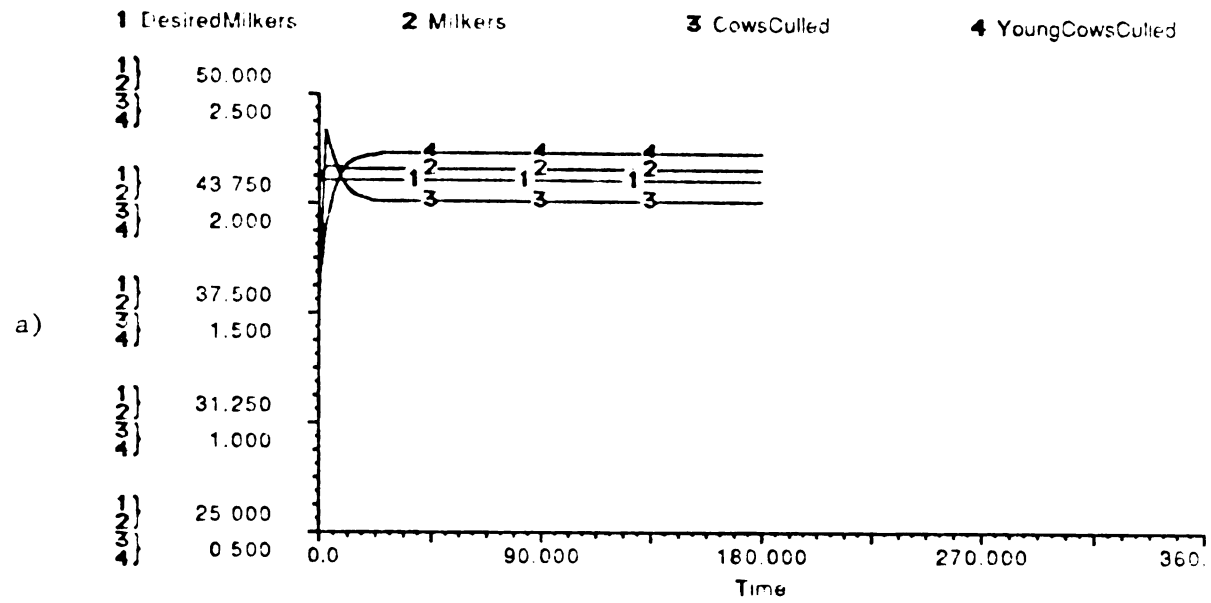
Under the hypothetical conditions of this model, this SOP will permit the farmer to attain the Desired Milker

Table 7.2b: Constant Purchases SOP, Constrained Stock, Run IIB.

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milker goal: Constant, 45 Milkers

Initial Value of State Variable	Variable	Final Value of State Variable
25.0	Calves	21.7
45.0	Heifers	45.7
15.0	Young Cows	20.4
30.0	Cows	25.3
45.0	Milkers	45.7

Time to Steady State: 0 months



Figures 7.6a-b: Constrained Stock, No Purchases, Run IIB.

goal. Milkers, in fact will exceed Desired Milkers because the SOP introduces slightly more "animal" than needed. Excess Cows are being culled as a result (Figure 7.6a and Table 7.2b). There is also a slight excess of Heifers as the maturing animals cannot be removed fast enough (Figure 7.6b and Table 7.2b). These types of errors are called steady state errors and are the differences between goals and actual levels when the system reaches equilibrium.

7.3.3 Run IIC, Constant Purchases SOP, Expand the Herd

A reasonable shock to this dairy herd system would be to expand the operation significantly. The forces leading to the decision to significantly expand could be made endogenous to this model, although it would mean modeling the farmer's "personal" goals and values. The decision to expand the operation can come from sources other than a desire to profit maximize. For example, if a farmer wishes to take advantage of new technology to minimize his physical strain, capital will need to be borrowed for the purchase. The cash flow requirements of the borrowed capital will likely require a larger milking herd. If a farmer wishes to bring a son into the business, perhaps as a partner, then more milking animals will be needed to generate sufficient incomes for the two owners. Neither of these two examples involve profit maximization, and if the loans can be arranged the expansion would likely occur.

Holding all of these considerations aside, the simple solution is adopted in this set of runs whereby the dairy model is shocked with an expansion of the herd to 90 milking animals in month 60. The exact timing of this expansion would be hard to predict correctly for a real farm even if assuming profit maximization. This problem is avoided by assuming that something is going on in the farm in month 60 that leads to this desire to expand.

In addition to the expansionary shock, which is initiated by the purchase of 45 Young Cows, other changes in the model need to be made to accommodate the expansion. The constraints on the maximum number of Calves and Heifers is raised proportionately. The SOP on the purchase of Young Cows is changed from two animals per month to four. Figures 7.7 a, b, c, and d are graphs of the simulation results. The run is summarized in Table 7.2c.

Before month 60 the state variables follow the same pattern as the previous run. In month 60 a sharp increase in Desired Milkers occurs (Figure 7.7a). The expansionary purchases of Young Cows raises Milkers up to this level at the same time. The increase in Young Cows also leads to the dramatic increase in Young Cows being Culled, which temporarily pulls down Milkers below the goal. In less than 15 months, by month 75, Milkers is slightly in excess of Desired Milkers.

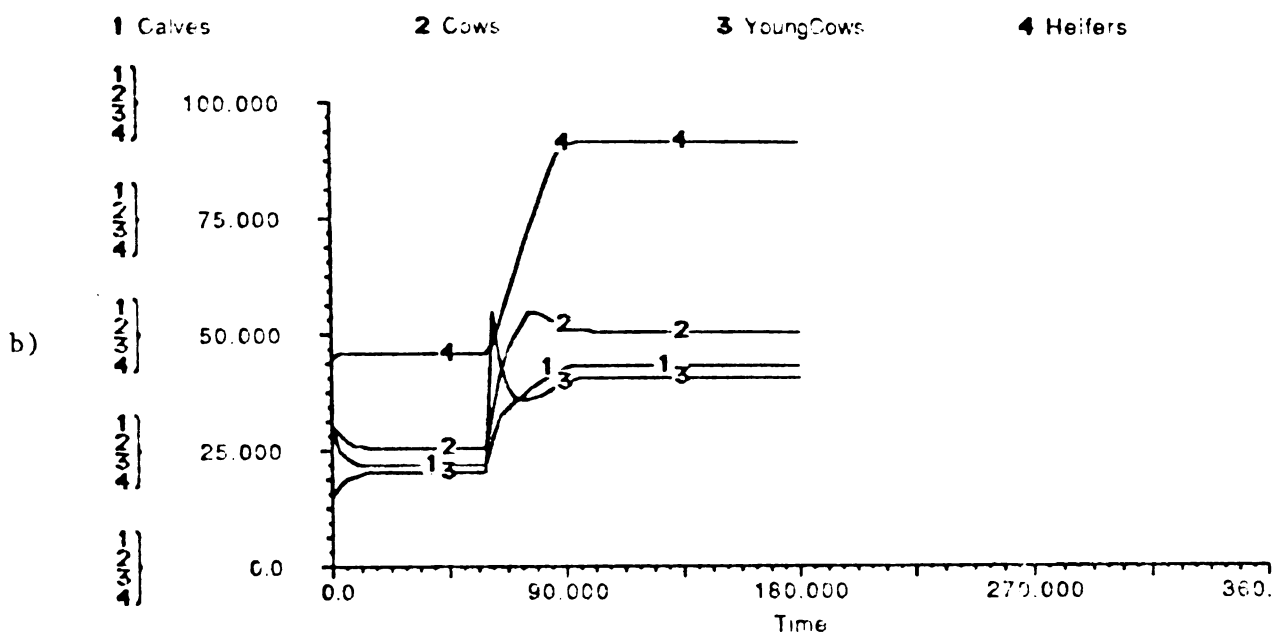
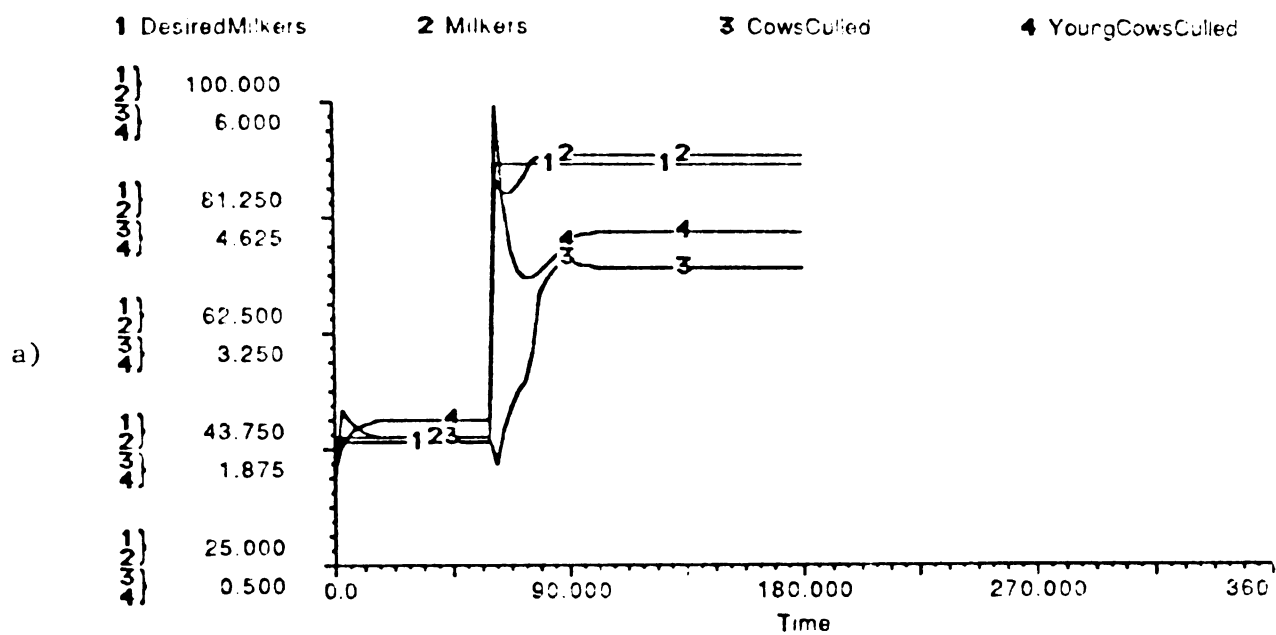
Table 7.2c: Constant Purchases, Expansion in Month 60
(Exogenous Shock), Run IIC

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milker goal: 45 animals until month 59, 90 cows thereafter
 - Constraint on Heifers: 45 animals until month 59, 90 thereafter
 - Constraint on Calves: 30 animals until month 59, 60 thereafter
 - SOP on Purchases of Young Cows: 2 animals per month 59, 4 animals per month thereafter

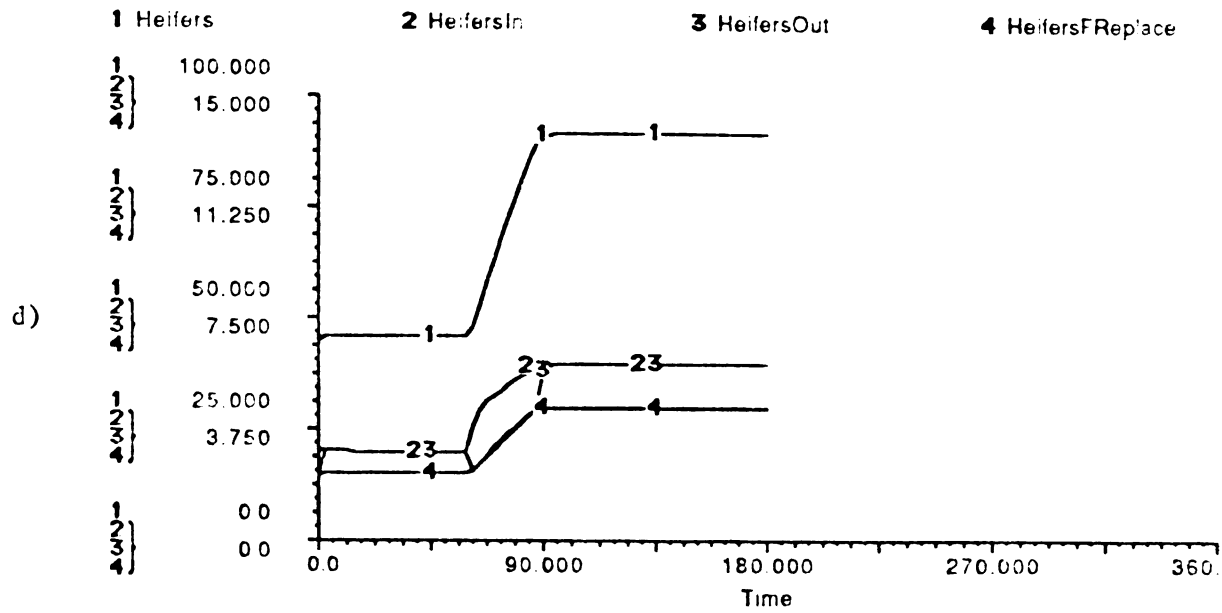
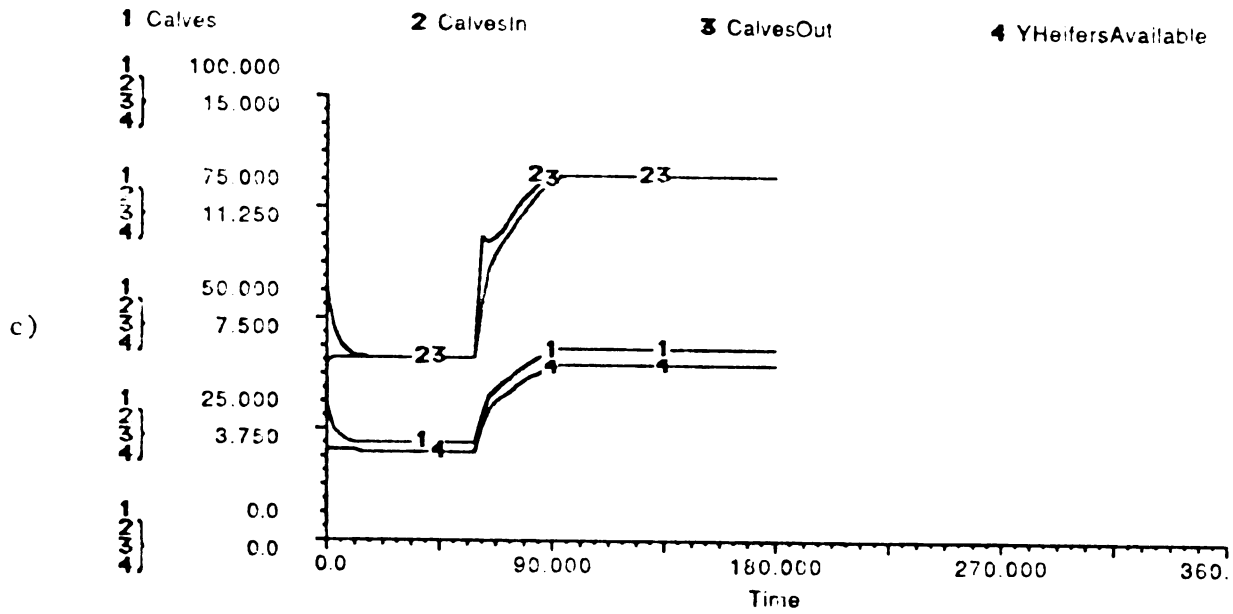
Initial Value of State Variable	Variable	Final Value of State Variable
30.0	Calves	43.2
45.0	Heifers	91.4
15.0	Young Cows	40.7
30.0	Cows	50.7
45.0	Milkers	91.4

Time to Meet Desired Milker goal after expansion: 15 months

The herd is able to recover because of the increase in the replacement stock which occurs in response to the births from the increase number of Milkers. Calves In (Figure 7.7c) rises just as dramatically as the number of Milkers, leading to greater numbers of Young Heifers Available for replacement. The rapid rise in Heifers and Heifers For Replacement in turn increase the milking herd size (Figure 7.7d). Once the number of Milkers stabilizes above Desired Milkers it is the SOP of four purchases per month that keeps the system stable.



Figures 7.7a-b: Constant Purchases, Expansion in Month 60 (Exogenous Shock), Run IIC.



Figures 7.7c-d: Constant Purchases, Expansion in Month 60 (Exogenous Shock), Run IIC.

7.3.4 Run IID, Constant Purchases, Expand Young Milkers and Heifers

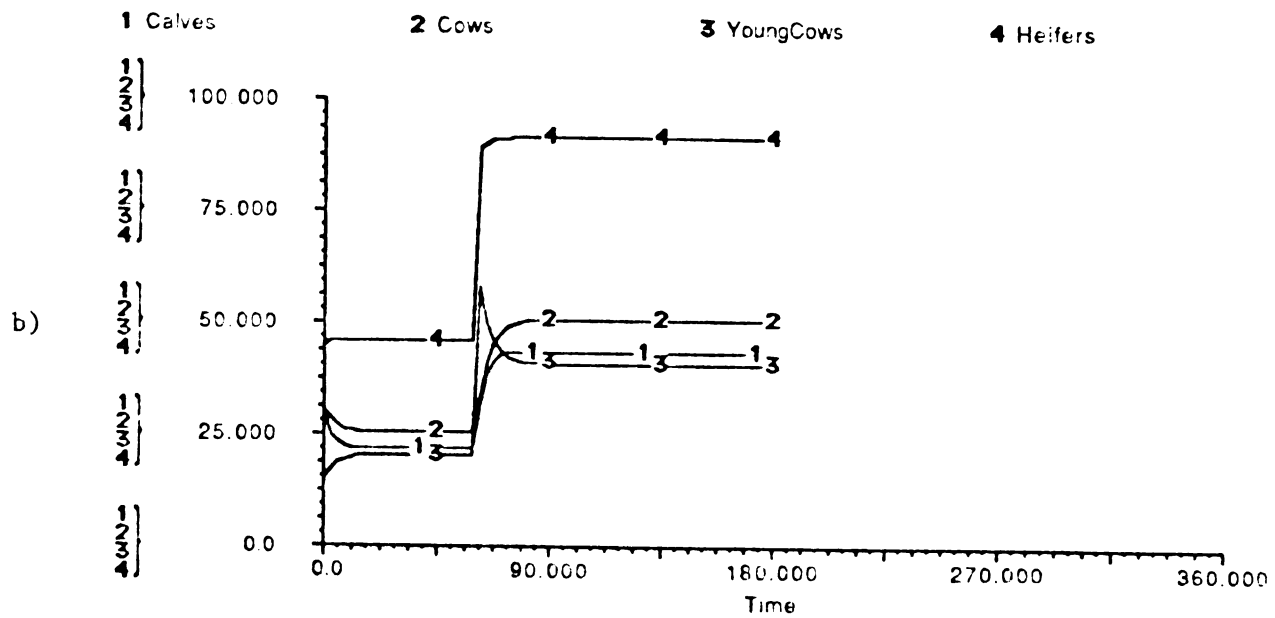
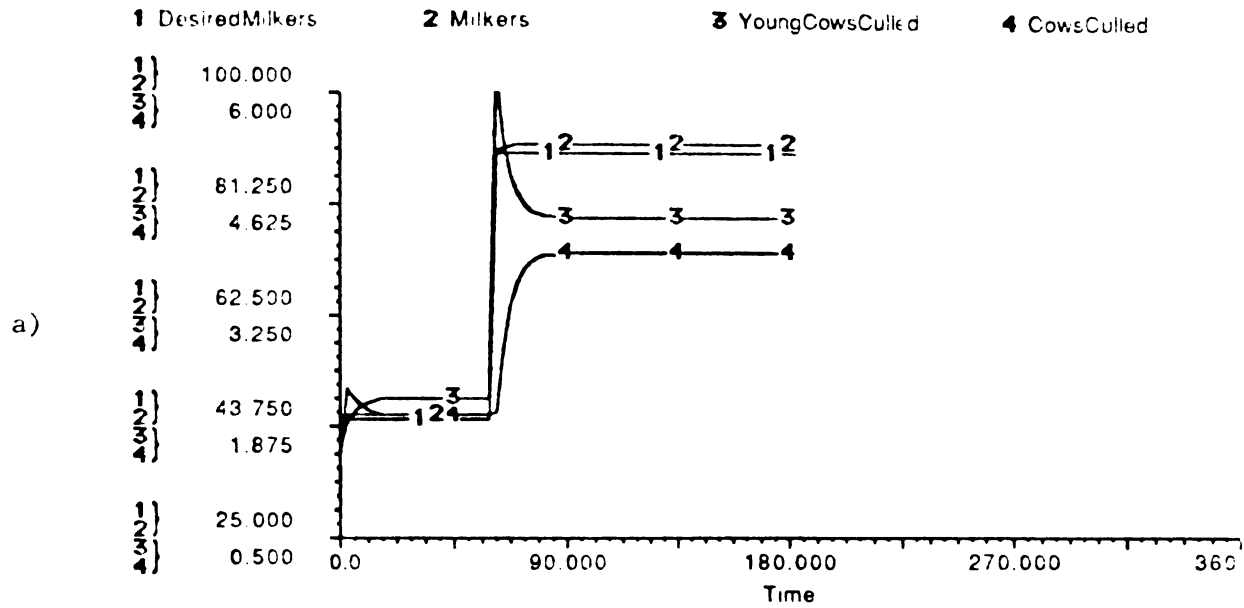
The sharpness in the dip in Milkers immediately following expansion in the previous run could cause the farmer to over react. If the farmer does not want to lose this many milking animals, one corrective policy would be to purchase all of the needed replacement Heifers at the time of purchase of the Young Cows. Figures 7.8 a through d present this scenario and demonstrate that the purchases of Heifers permits Milkers to immediately meet the Desired Milkers goal. The response of the variables in all four graphs is correspondingly rapid.

Table 7.2d: Constant Purchases, Expand Young Cows and Heifers in Month 60; Run IID

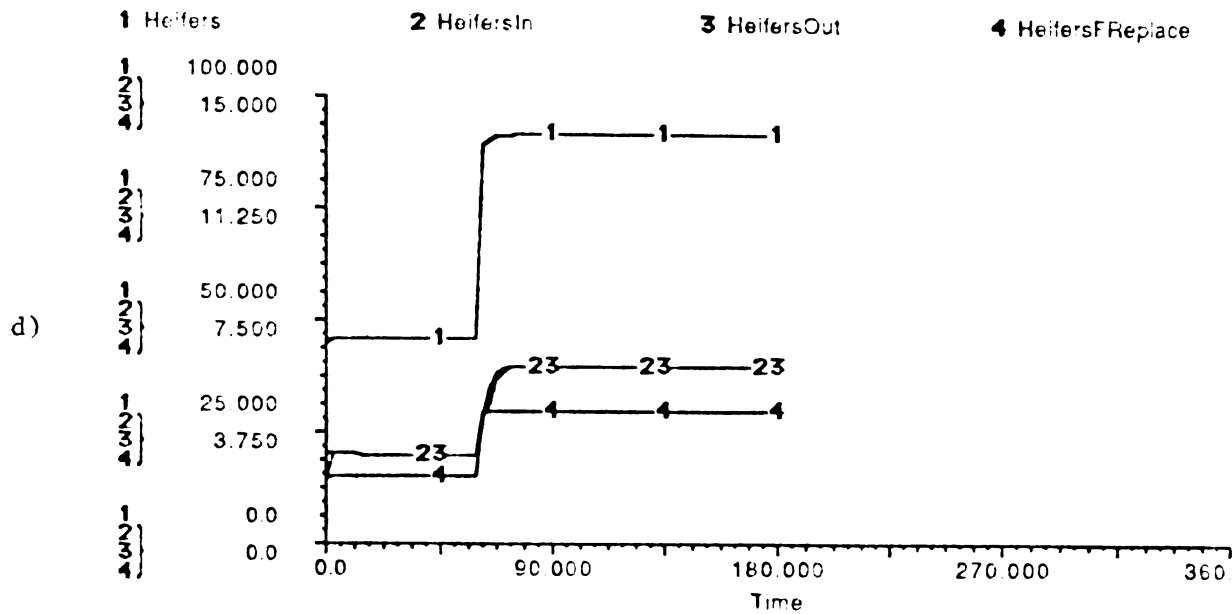
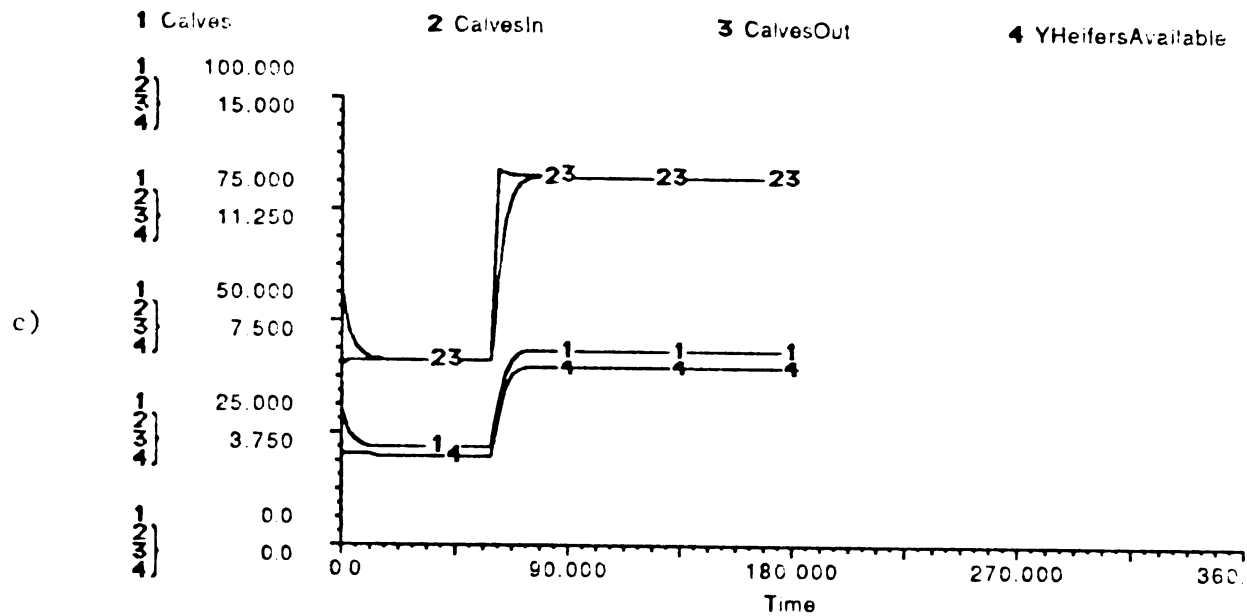
-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milker goal: 45 animals until month 59,
90 thereafter
 - Constraints on Calves and Heifers: Same as IIC

Initial Value of State Variable	Variable	Final Value of State Variable
30.0	Calves	43.2
45.0	Heifers	91.4
15.0	Young Cows	40.7
30.0	Cows	50.7
45.0	Milkers	91.4

Time to Meet Desired Milker goal after expansion: 0 months



Figures 7.8a-b: Constant Purchases, Expand the Herd with Heifers and Young Cows, Run IID.



Figures 7.8c-d: Constant Purchases, Expand the Herd with Heifers and Young Cows, Run IID.

7.3.5 Run IIE, Constant Purchases, Expansion only in Heifers

A better strategy for expansion might be to expand only in Heifers and then let the replacement herd generate the Milkers. The lag of Milkers behind Desired Milkers in this case is 17 months (Figure 7.9a and Table 7.2e), rather than 15 months when Young Cows were purchased for the expansion. The immediate increase in Heifers pulls the other states up during this period without the drastic dip in milker numbers experienced in Run IIC.

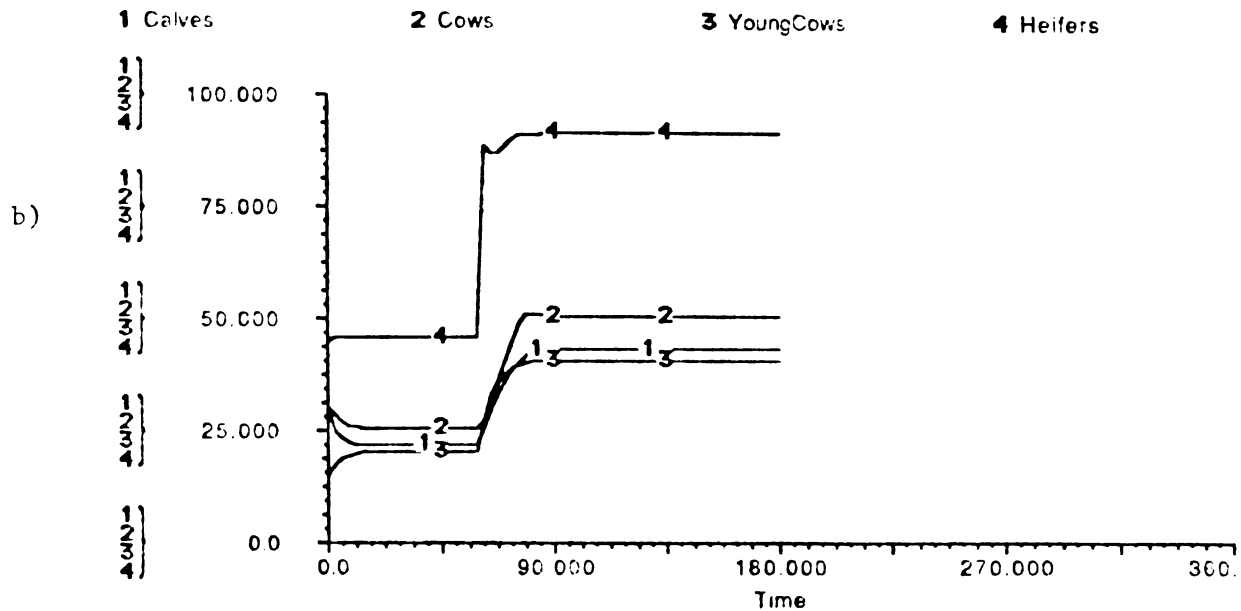
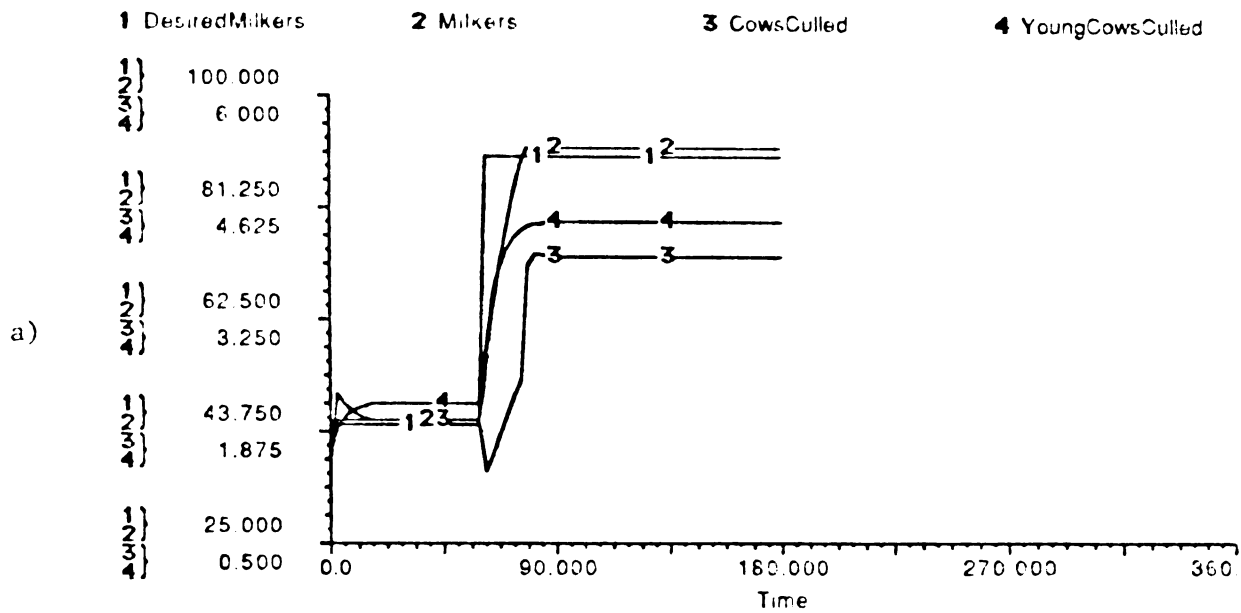
Table 7.2e: Constant Purchases, Expand Herd With Only Heifers Only in Month 60, Run IIE

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milker goal: 45 animals until month 59,
90 thereafter
 - Constraints on Calves and Heifers: Same as IIC

Initial Value of State Variable	Variable	Final Value of State Variable
30.0	Calves	43.2
45.0	Heifers	91.4
15.0	Young Cows	40.7
30.0	Cows	50.7
45.0	Milkers	91.4

Time to Meet Desired Milker goal after expansion: 17 months

This type of expansion may be cheaper than either the purchase of Young Cows or the purchase of Young Cows and Heifers. In comparison to adding Young Cows, only two months are added until the goal can be reached but there



Figures 7.9a-b: Constant Purchases, Expand Herd with Heifers Only, in Month 60, Run IIE.

is no loss due to the culling of milking animals. When purchasing only Heifers is compared to expanding with both Young Cows and Heifers, the cost of purchasing the Young Cows is avoided, although there is the 17 month lag of Milkers behind Desired Milkers. The purchases of Heifers appears to be a viable expansion strategy under certain conditions.

7.4 SOP on Variable Purchases of Replacements

A farmer may decide to calculate each month the number of animals he needs to purchase based on the difference between the current number of Milkers and the Desired Milkers goal. The milking animals purchased in this model are assumed to be young cows. The calculation of Young Cows Purchased in the model involves a delay of two months to account for some time to perceive and act on a shortage of Milkers. This delay should give different results from those with the constant purchases SOP because making the calculation each month may result in less over-purchasing.

7.4.1 Run IIIA, Baseline for Variable Purchases

The run begins with the same replacement stock levels as used in the constant purchases SOP. It is assumed that it takes the farmer two months to perceive and be able to act on the shortage of animals. Figure 7.10a shows that Milkers is not able to meet Desired Milkers when the system

Table 7.3a: Baseline for Variable Purchases, Run IIIA

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milkers: Constant, 45 animals
 - Time to Purchase Young Cows: 2 months

Initial Values of Variables	Variable	Final Values of Variables
30	Calves	20.9
45	Heifers	45.6
15	Young Cows	15.1
30	Cows	29.0
45	Milkers	44.1
N.A.	Desired Milker Gap	.90
0	Young Cows Purchased	.90
N.A.	Heifers for Replacement	2.2
N.A.	Young Cows Culled	1.7
N.A.	Cows Culled	1.5

Table 7.3b: Altered Time Constant from Baseline, Run IIIB

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milkers: Constant, 45 animals
 - Time to Purchase Young Cows: 4 months

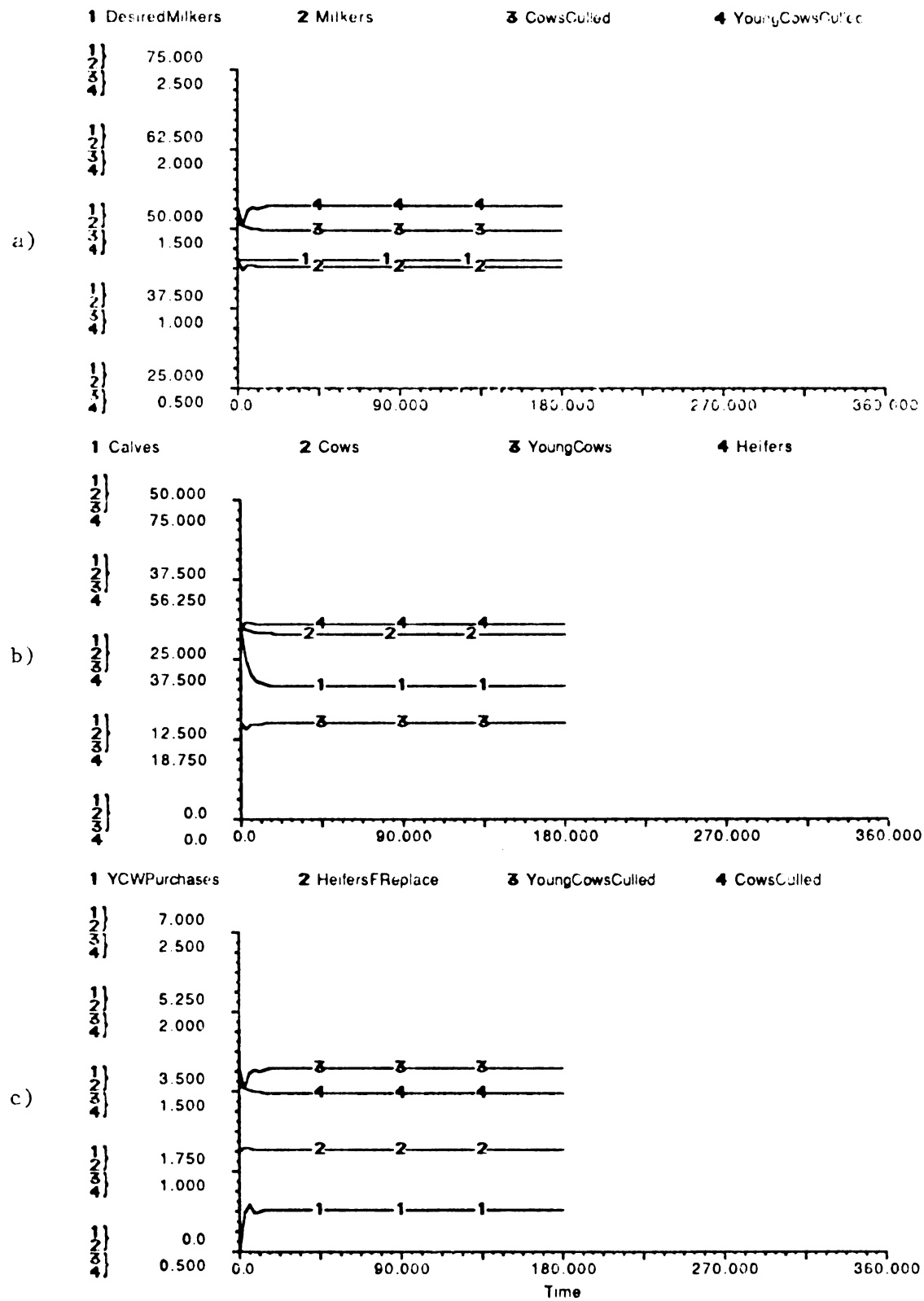
Initial Value of Variable	Variable	Final Value of Variables
30	Calves	20.9
45	Heifers	45.6
15	Young Cows	15.1
30	Cows	29.0
45	Milkers	44.1
N.A.	Desired Milker Gap	.90
N.A.	Young Cows Purchased	.90
N.A.	Heifers for Replacement	2.2
N.A.	Young Cows Culled	1.7
N.A.	Cows Culled	1.5

has reached steady state. The steady state error is given by the Desired Milker Gap and is equal to (approximately) one cow. The steady state error results from the interplay of the purchasing delay, death losses, cull rates and birth rates.

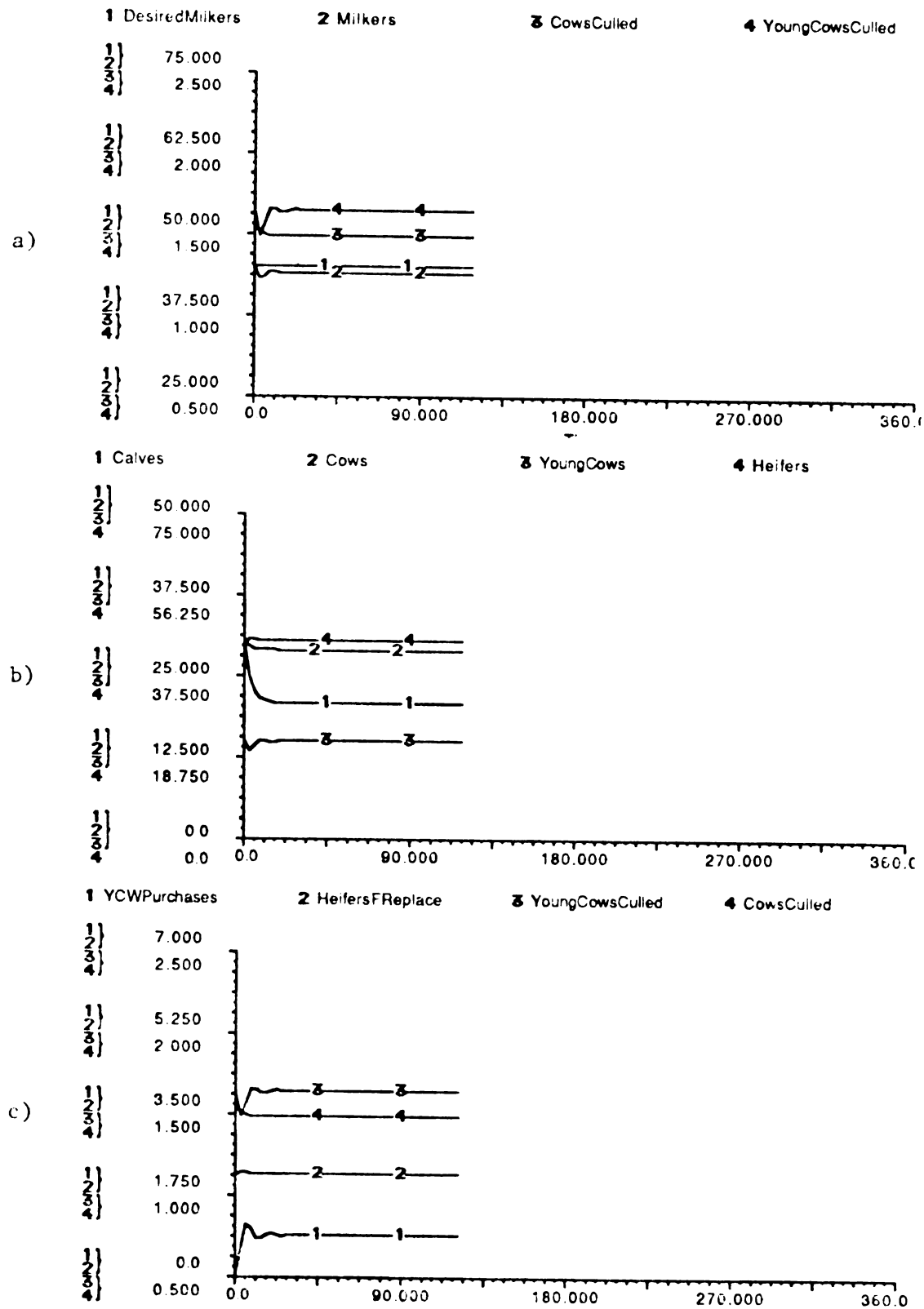
7.4.2 Run IIIB, Increasing the Purchasing Delay to Four Months

The steady state difference between Milkers and Desired Milkers is the same when the purchasing delay is four and two months. All of the final states for the two runs are also identical (Tables 7.3 a and b). The only difference between the two runs is the initial dip in the number of Young Cows before purchases of Young Cows returns the herd to the steady state. Young Cows in this run declines slightly more when the purchase delay was only two months (comparing Figure 7.11b to Figure 7.10b).

The difference between Young Cow Purchases in this run (Figure 7.11) and the previous (Figure 7.10c) is the cause of the increased decline. It takes slightly longer for purchases to reach an adequate level when the delay is four months. As a result, the dip in Milkers in this run is also slightly greater than under the previous conditions, although the difference is almost imperceptible in the figures (comparing 7.11a to 7.10a). The main point is that altering the value of the time delay has no impact on the



Figures 7.10a-c: Baseline for Variable Purchases, Run IIIA.



Figures 11a-c: Altered Time Constant from Baseline, Run III B.

steady state condition.

The variable purchases SOP (Run III) does not perform as well as the constant purchases SOP (Run II) if performance is judged by ability to meet the Desired Milker goal. Although the Desired Milker Gap of one animal when purchases are variable is only two percent of the goal, the absolute value of the gap will amount to more animals as the herd size increases. If two percent error is acceptable then the variable purchases SOP may be preferable to the constant SOP since the variable purchases does not result in over-purchases at any time.

7.4.3 Run IIIC, Variable Purchases, Expansion in Month 60

Expansion occurs in this run by purchasing Young Cows in month 60. Desired Milkers and the constraints on replacement stock are also increased. As shown in Figure 7.12a, Milkers falls off from Desired Milkers for approximately 15 months, but eventually returns to a steady state error of approximately 2 animals (Desired Milker Gap in Table 7.3c). The initial dip in Milkers results from the drop in Young Cows as they are culled in greater numbers. The drop in Young Cows can be seen in Figure 7.12b and the increase in the cull rate in Figure 7.12c. Animals are also moving out of Young Cows resulting in a growth in the number of Cows (Figure 7.12b). The variable purchases SOP also tries to compensate for the deficit in Milkers by purchasing more animals (Figure 7.12c), but the herd will

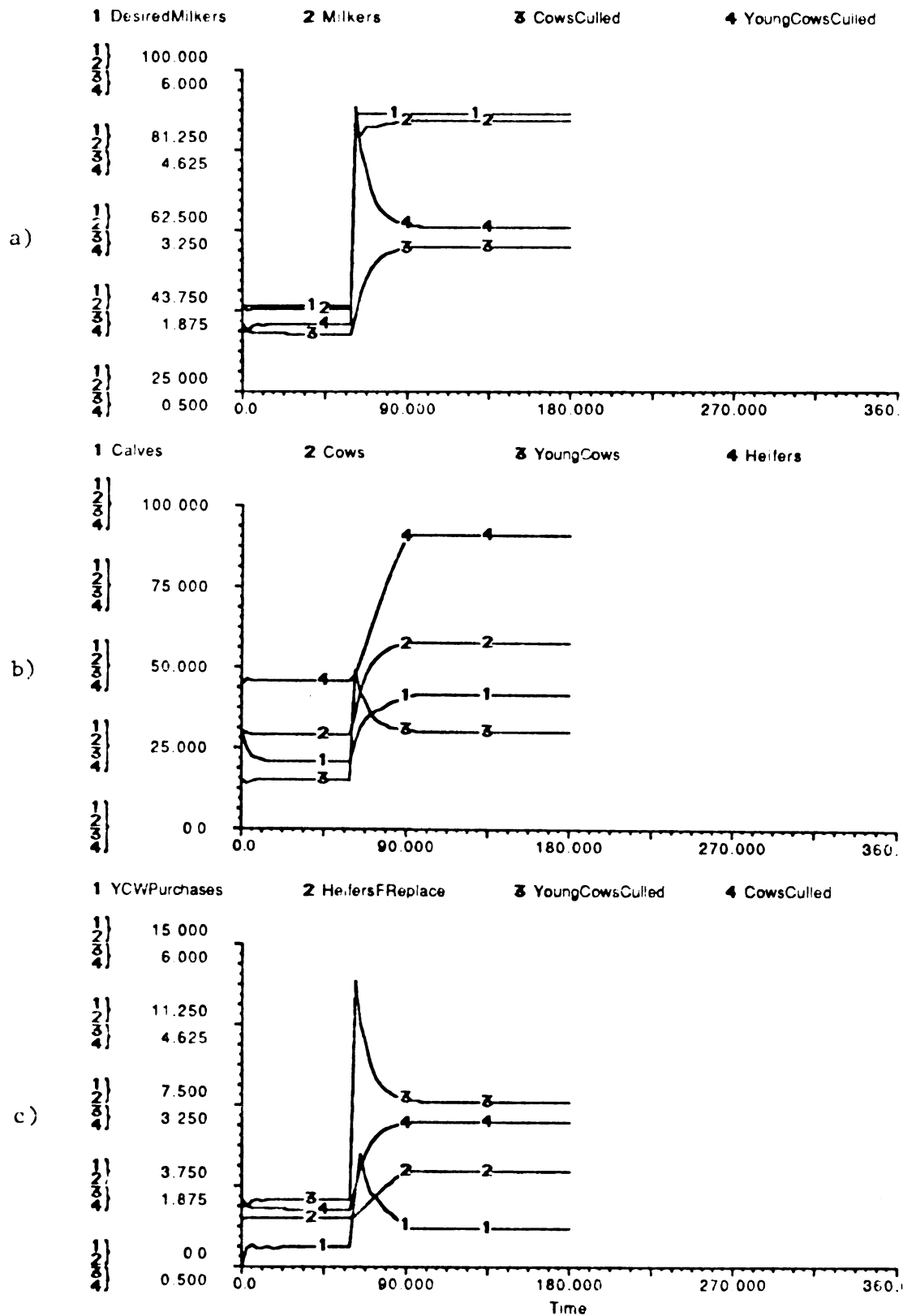
Table 7.3c: Baseline with Expansion in Month 60, Run IIIC

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milkers: 45 animals until month 59, 90 animals thereafter
 - Time to Purchase Young Cows: 2 months

Initial Value of Variable	Variable	Final Value of Variables
30	Calves	41.7
45	Heifers	91.2
15	Young Cows	30.3
30	Cows	57.9
45	Milkers	88.2
N.A.	Desired Milker Gap	1.80
N.A.	Young Cows Purchased	1.80
N.A.	Heifers for Replacement	4.5
N.A.	Young Cows Culled	3.3
N.A.	Cows Culled	3.0

not reach the steady state until there is a sufficient number of Heifers.

No analysis of expansion by the purchase of Heifers is performed with the Young Cow variable purchases SOP since the results will essentially be identical to those obtained in Run IIE (except for some steady state error).



Figures 7.12a-c: Variable Purchases with Expansion in Month 60, Run IIIIC.

7.5 Linking the Desired Milker Goal to Feedback

Although introducing meaningful feedback to the Desired Milker goal from the financial performance of the farm should result in some interesting dynamic results, this would involve linking the herd to finance and cost components. Leaving this type of analysis for future work, some dynamic feedback effects can be observed by linking the ability of the herd to meet the Desired Milker goal to the goal itself.

Figure 7.13 is a causal loop diagram of one conception of linking Desired Milkers to feedback. A new definition of Desired Milkers is used in this formulation. Desired Milkers Base represents the basic number of Milkers the farmer wants to manage, while Desired Milkers Adjusted represents an adjustment of the Base as a result of feedback. The difference between Desired Milkers Adjusted and Milkers determines the Desired Milker Gap. This is the gap used to determine how many Young Cows should be purchased (as in Run III). A perceptual and procedural delay occurs between the gap and purchases. The gap can also be used to adjust Desired Milkers Adjusted. As the gap increases an increase will occur in the average degree of error which leads to an increase in the Desired Milkers Adjusted goal. This, in turn leads to purchases of Young Cows. The averaging of the Desired Milker Gap implies a lag or delay.

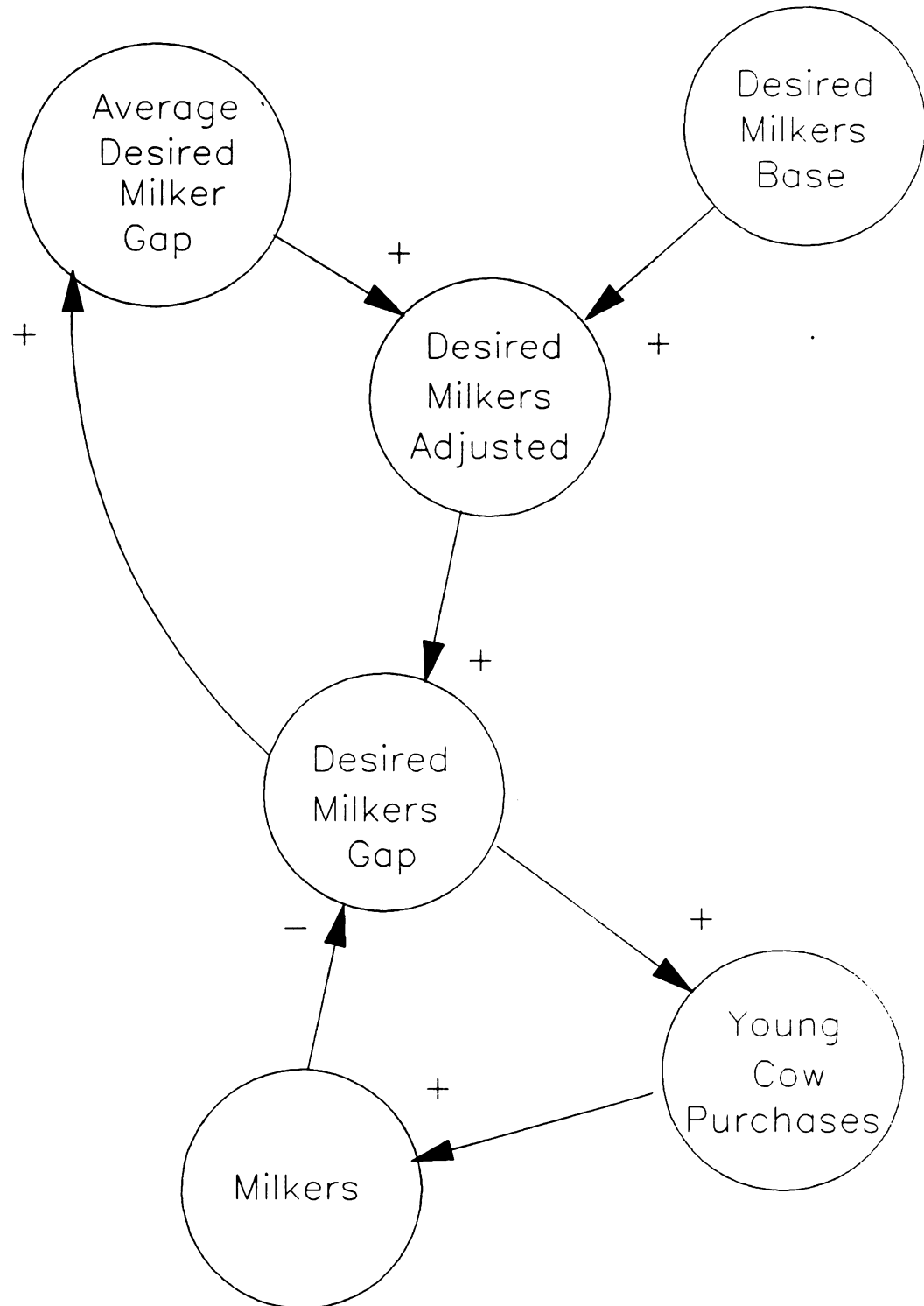


Figure 7.13; Causal Loop Diagram Linking Feedback to Desired Milker Goal

Using the degree of error to change the goal would make sense if the hypothesized farmer were responding to too few Milkers by trying to increase the size of the operation and not by altering management techniques. This formulation is analogous to farmers responding to inadequate profits by increasing herd size and not improving management practices.

Two principle loops result from this structure; the loop leading to purchases and a decrease in the gap and a loop linking the gap to the goal. The distinction between Desired Milkers Base and Desired Milkers Adjusted is important. If Desired Milkers were not held back by a base, as a gap begins to appear and the purchases of Young Cows lags behind the increase in the Desired Milker goal, an upward spiral would result. The system would be unstable with the goal being chased but never caught by the actual number of Milkers. The assumption is that the farmer will remember that he has a basic goal and that this remains invariant even if there is not enough Milkers.

Given this base, the time path of the simulation of this model depends on the degree of delay in the purchases of Young Cows relative to the time it takes to average the experience of the Desired Milker Gap.

7.5.1 Run IVA, B, and C, Analysis of Averaging Times for Feedback

These three runs, summarized in one table (Table 7.4a), explore the impact of different averaging times for the Desired Milker Gap on the herd. One run was made for averaging times of 6, 4, and 2 months. The simulations show that the system is not unstable with any of these averaging times, although the greatest degree of stability results when 6 months is used. Figures 7.14a through c compare the time paths of these three runs.

Table 7.4a: Analysis of Averaging Times for Feedback: 6, 4 and 2 months, Runs IVA, IVB and IVC

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milkers: Initial 45 animals, changes according to feedback
 - Time to Purchase Young Animals: 2 months
 - Time to Average Desired Milker Gap Ratio: 6, 4 and 2 months

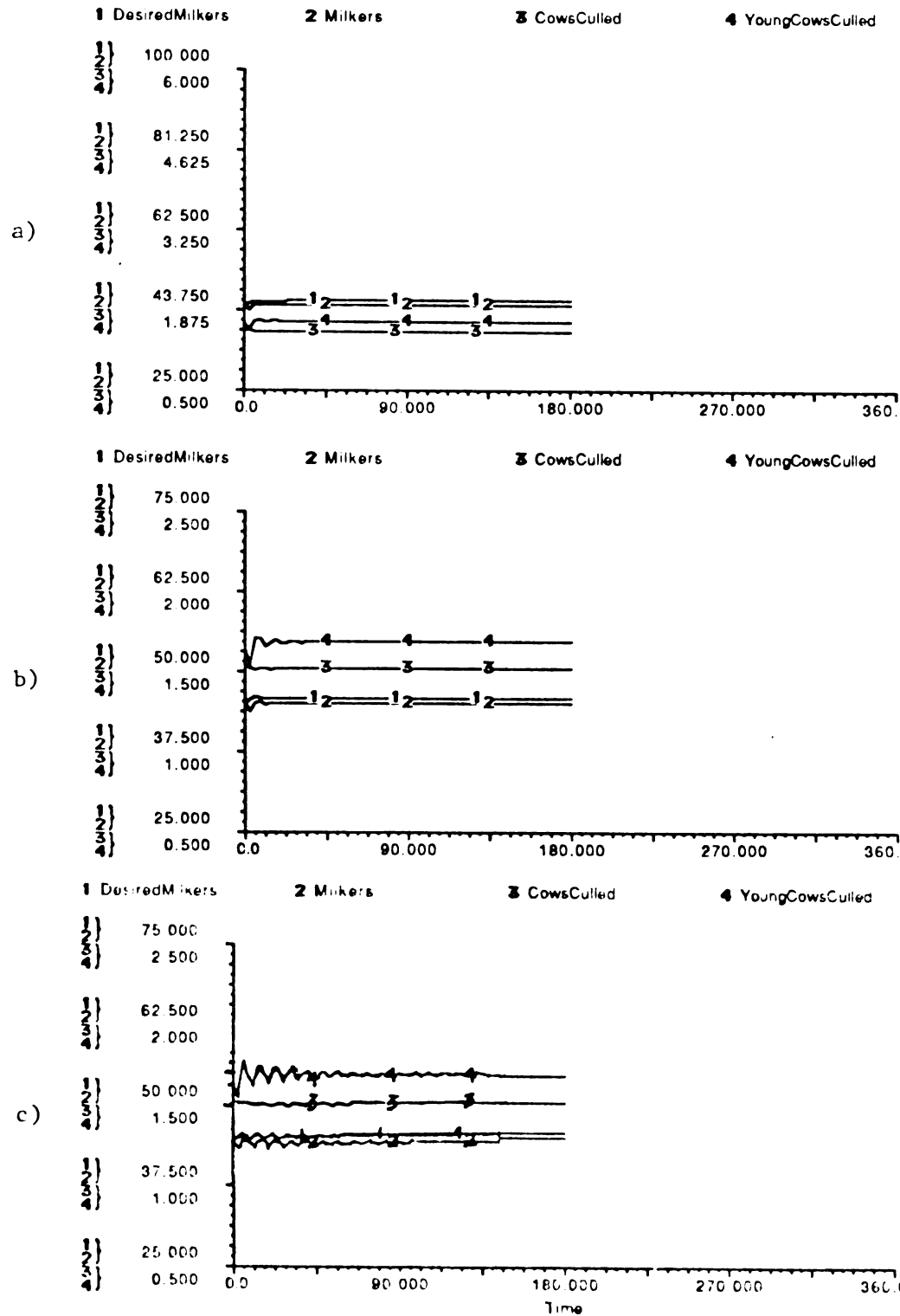
Initial Values of Variables

	Variable	Final Values of Variables		
		6 months	4 months	2 months
30	Calves	21.3	21.3	21.3
45	Heifers	46.5	46.5	46.5
15	Young Cows	15.4	15.4	15.4
30	Cows	29.6	29.6	29.6
45	Milkers	45.0	45.0	45.0
N.A.	Desired Milker Gap	.92	.92	.92
0	Young Cow Purchases	.92	.92	.92
0	DMG Ratio	.02	.02	.02
45	Desired Milkers	45.9	45.9	45.9

Time to Reach Steady State: See text

In Figure 7.14a the averaging time is 6 months. A slight dip in Milkers occurs at the start of the simulation and the Desired Milker goal is forced upward slightly (see the final value for Desired Milkers in Table 7.4a). In comparison, decreasing the averaging time to 4 months (Figure 7.14b) causes a little more oscillation, although the steady state is identical to the previous run. In Figure 7.14c, with an averaging time of 2 months even more oscillation occurs and the system does not stabilize until after 100 months. Still, once this system reaches steady state it is identical to the previous two runs. The instability that occurs when two months is used is also evident in the quantity of Young Cows Purchased and Young Cows Culled (Figure 7.14). The fact that the averaging time for the ratio of the gap is the same as the delay on the purchases of Young Cows is the likely source of this instability.

At steady state, the milking herd with any of these averaging times remains at 45 animals, and the Desired Milker Adjusted Goal stays at approximately 50 animals. The implication of the results from the runs in III were that the goal would have to be raised above 45 if the herd were going to reach 45. In contrast, these runs demonstrate that the degree of steady state error can be used to adjust the goal to reach the Desired Milker Base level.



Figures 7.14a-c: The Effect of Differing Averaging Times for Feedback; 6, 4, and 2 months, Runs IVA, IVB, IVC.

7.5.2 Run IVD, Linked Goal, Constant SOP on Purchases, Expand with Heifers

The runs in II were made with constant purchases of Young Cows. Run IIE shocked this system by expanding the herd with 45 Heifers and increasing Desired Milkers to 90 animals. As depicted in Figure 7.9a, Milkers lags behind Desired Milkers for 17 months. What if this type of shock was applied to the system when feedback from the performance relative to Desired Milkers is incorporated?

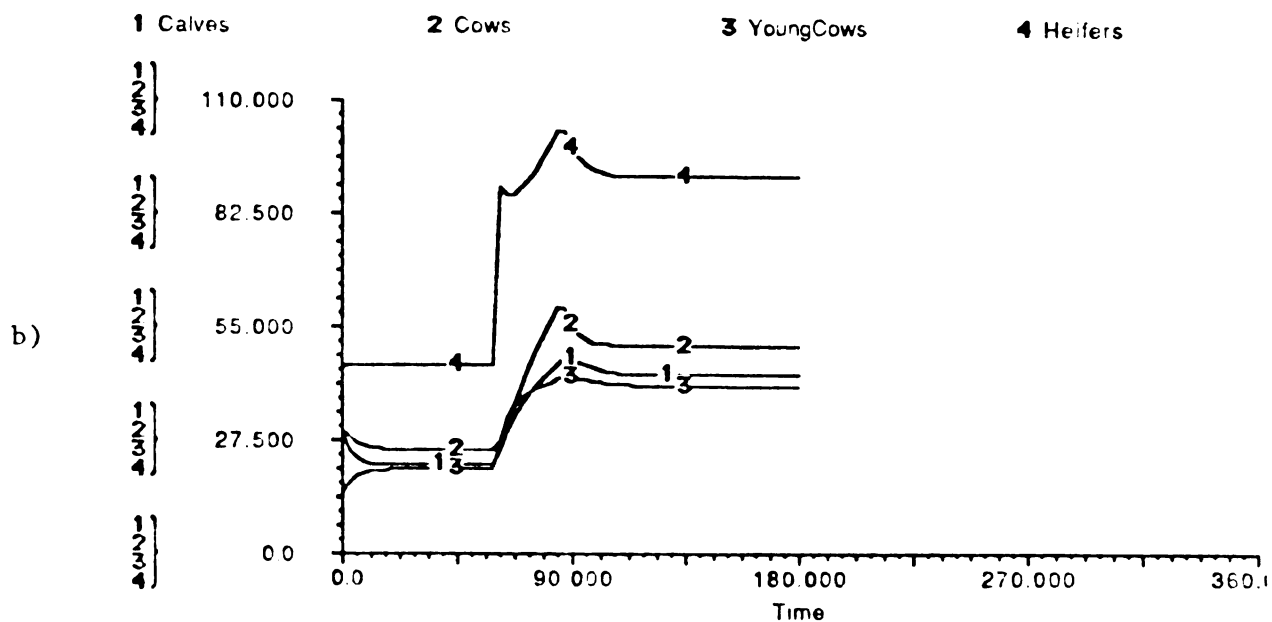
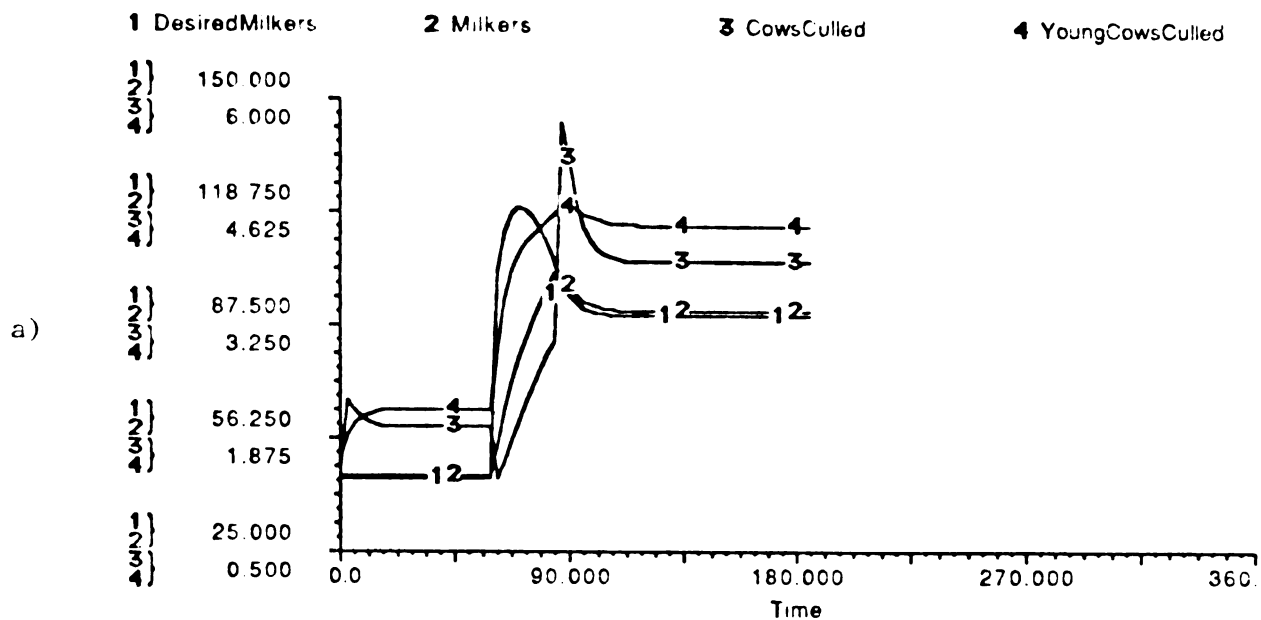
Figures 7.15 a and b and Table 7.4b present the results of this simulation. The increase in Heifers registers immediately (Figure 7.15b). Although Young Cows and Cows

Table 7.4b: Endogenous Desired Milkers, Constant SOP on Purchases, Expand with Heifers

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milkers: Initially 45 animals, changes according to feedback. Expands to 90 animals in month 60.
 - Time to Purchase Young Animals: N.A.
 - Time to Average Desired Milker Gap Ratio: 6 months
 - SOP on Purchases: Constant, 2 animals per month

Initial Values of Variables	Variable	Final Values of Variables
30	Calves	43.4
45	Heifers	91.5
15	Young Cows	40.8
30	Cows	50.6
45	Milkers	91.4
N.A.	Desired Milker Gap	-1.4
0	Young Cow Purchases	0.0
0	DMG Ratio	0.0
45	Desired Milkers	90.0

Months to Reach 90 Milkers after expansion: 16 months



Figures 7.15a-b: Endogenous Desired Milkers, Constant SOP on Purchases, Expand with Heifers, Run IVD.

both increase, the Desired Milker Gap leads to a rapid increase in Desired Milkers Adjusted (Figure 7.15a). But the gradual accumulation of Heifers reduces the gap relative to Desired Milkers Base (not depicted), so that Desired Milkers Adjusted falls and Milkers rises. Sixteen months after the expansion, Milkers reaches 90 animals, and at this time Desired Milkers Adjusted has risen to 116 animals. Milkers are culled as both this variable and Desired Milkers Adjusted gets pulled down to the base of 90 animals.

7.5.3 Run IVE, Linked Goal, Variable Purchases SOP, Expand with Young Cows

Run IIIC explores the effects of expanding the herd with the purchase of Young Cows when the farmer is making monthly purchases of Young Cows to fill the Desired Milker Gap. There was essentially no lag between Milkers and Desired Milkers in this run, except for steady state error (Figure 7.12a). Essentially the same result occurs in Run IVE, when 45 Young Cows are purchased in month 60 and the Desired Milker Gap feedback is linked to Desired Milkers. The only striking result is that the number of Young Cows Culled rises greatly during the period of adjustment of the numbers of Milkers and Young Cows (Figures 7.16a and b). Young Cow Purchases also remain high for a period (approximately 24 months) after the expansion to fill any

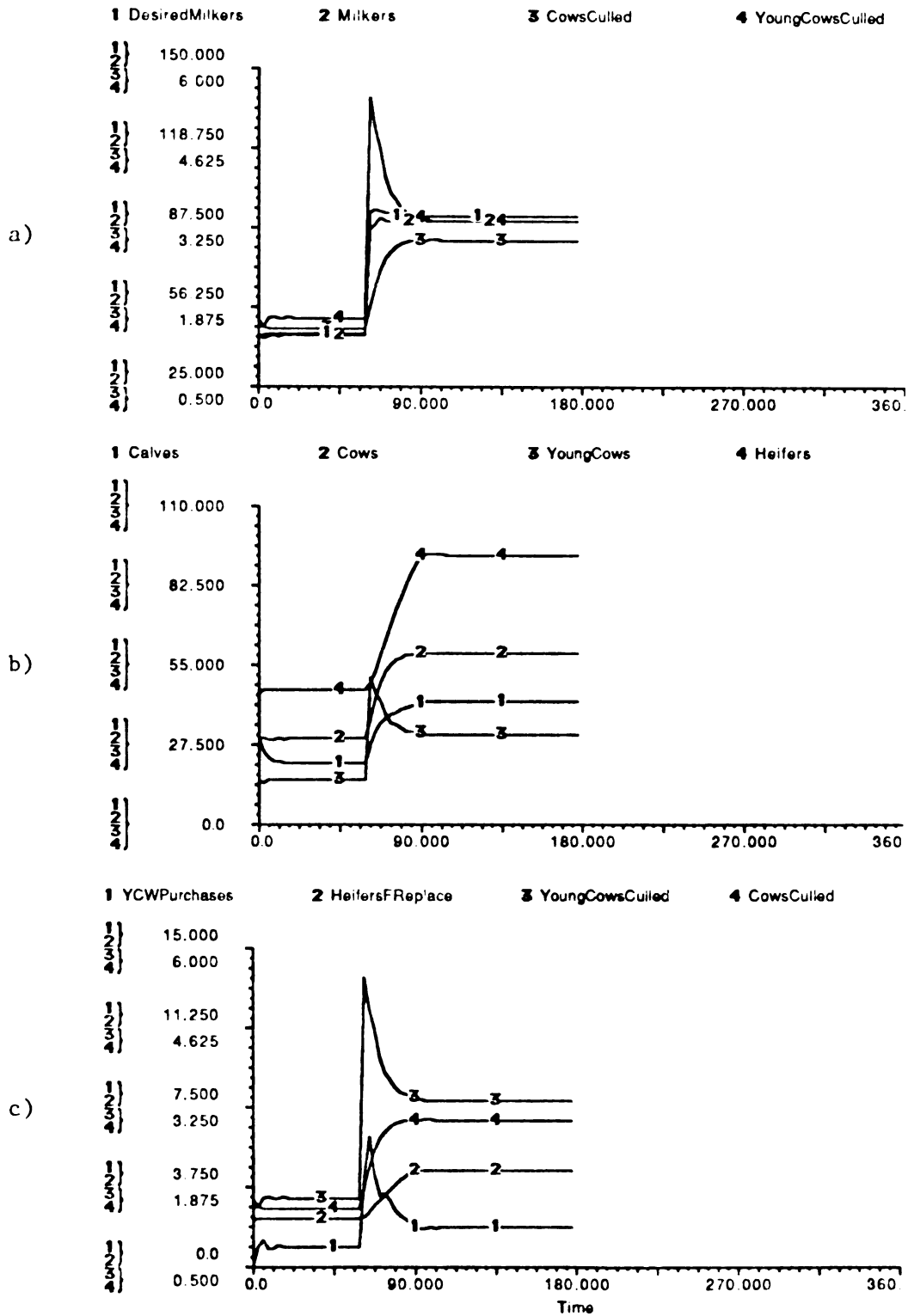
Table 7.4c: Endogenous Desired Milkers, Variable SOP on Purchases of Young Cows to 90; Run IVE

-
- Cull Rates: Standard
 - Death Losses: Standard
 - Desired Milkers: Initially 45 animals, changes according to feedback. Expands to 90 animals in month 60.
 - Time to Purchase Young Animals: 2 months
 - Time to Average Desired Milker Gap Ratio: 6 months
 - SOP on Purchases: Variable, linked to Desired Milker Gap

Initial Value of Variables	Variable	Final Values of Variables
30	Calves	42.6
45	Heifers	93.1
15	Young Cows	30.8
30	Cows	59.1
45	Milkers	90.0
N.A.	Desired Milker Gap	1.8
0	Young Cow Purchases	1.8
0	DMG Ratio	0.2
45	Desired Milkers	91.9

Months to Reach 90 Milkers after expansion: Essentially no time to attain the steady state error of 1.8 animals.

developing Desired Milker Gap while Young Cows and Cows balance out. Young Cow Purchases eventually settles down to a steady state level (Figure 7.16c)



Figures 7.16a-c: Endogenous Desired Milkers, Variable SOP on Purchases of Young Cows to 90, Run IVE.

7.6 Summary of Simulation Results

When the model is simulated without the purchases of replacement stock and with "baseline" death losses and cull rates (Run I), it takes approximately thirty years for Milkers to reach Desired Milkers. The lag is caused by the inadequate levels of on the farm replacement stock. Eventually enough stock is generated internally to meet the goal. If the average age of Cows is raised to 72 months the Desired Milker goal can be met in 5 years. These results indicate the need for purchases of replacements if the farmer cannot maintain or house sufficient numbers of Heifers and Calves.

The purchase of two Young Cows a month enables the farmer to meet the Desired Milker goal although some over purchasing of animals occurs (Run II). Attempting to expand to 90 milkers by purchasing Young Cows leads to a 15 month lag until the new Desired Milker goal is reached. Expansion by the purchase of Young Cows and Heifers results in no lag. Expansion by the purchase of only Heifers leads to a 17 month lag, but there are no excess milking animals and therefore no culling of unnecessary Milkers.

Rather than purchasing the same number of Young Cows for replacements each month, some farmers may base their purchases on the gap between the number of Milkers and the Desired Milkers goal. This SOP, used in Run III, leads to an inability to meet the Desired Milker goal. The gap never

disappears in steady state and represents two percent of Desired Milkers. The steady state gap is attributable to the time it takes to perceive and arrange for the purchase of the Young Cows. Increasing this delay in perception does not alter the steady state consequences. Under the shock of expansion, Milkers lags behind Desired Milkers by 15 months which is the time it takes to accumulate an adequate quantity of replacement stock.

The gap between Desired Milkers and Milkers is used to alter Desired Milkers in Run IV, representing an attempt by the farmer to overcome the two percent steady state error when purchases are variable. Although there is an increase in instability if the time to average the gap information is too small, the herd behaves very similarly to the runs without the endogenous Desired Milker goal; a steady state gap of two percent still remains. Endogenizing this goal by linking it to the gap has very little new impact on the performance of the system.

7.7 Conclusions

The introduction to this chapter asks three questions:

- 1) Can STELLA be used to model a specific part of the dairy operation?
- 2) Can this model rely on the use of SOP's to guide the operation?
- 3) Could a model constructed in STELLA and oriented towards a specific problem be of use to agricultural economists?

Using the criteria of model viability-validity discussed in the introduction as the measurement standards, the runs in I indicate that the model is viable and valid. In turn, to whatever extent these criteria are considered appropriate, the answers to the first two questions can be considered positive.

The answer to question three is as subjective as the answers to the previous two, and depends on the person viewing the evidence. The only conclusion that really can be drawn from the results of Runs II-IV is that different herd management strategies under the conditions of stress from significant expansion of the milking herd will lead to specific and distinct results.

The implication, although not rigorously conclusive, is that STELLA is useful as a problem solving tool. As for the simulated response of the operator to the performance of the operation relative to the Desired Milker Goal, models of an entire range of management goal oriented behavior should be possible to construct. Such models, although useful for problems involving only one management goal/response, become particularly useful when a system of interacting management practices need to be explored in order to understand the management problem.

CHAPTER EIGHT
SUMMARY AND CONCLUSIONS: BEHAVIORAL MODELS AND
THE ISSUE OF MAXIMIZATION

8.1 The Primary Research Questions

The primary questions asked in this research are answered in Chapter Five. It was found, although not conclusively, that simulation models can be used to represent the standard operating procedures of firms in such a way so as to recreate much of their business behavior. The usefulness of these models for performing sector level policy analysis was found to be much less promising. While sector level models using behavioral theory have been constructed, the time and expense needed for their construction may be prohibitive. The problem lies in the lack of a universally applicable theory of economic behavior, so that a new theory needs to be created for every system considered. Some promise was found in the system dynamics models of Meadows, that combined the aggregative strengths of neo-classical theory with some behavioral/system dynamics constraints to create an apparently useful model of the hog industry.

The behavioral, systems simulation model of a Mid-Michigan dairy farm was never completed in this research. The time and effort that went into this model was significant, and contributed to the conclusion that although detailed behavioral models of a single-owner farm operation

are possible, building such models for sector level market analysis may require more resources than are practical for most situations.

A systems simulation model of the herd management portion of a dairy operation, constructed with the systems dynamics language STELLA, permitted the examination of a number of different management issues that may face a dairy operator. The results indicate that STELLA is a useful tool for the examination of on-farm management problems where farmer behavior needs to be represented by standard operating procedures not completely consistent with the assumptions of neo-classical theory.

8.2 A Return to the Issue of Maximization

Chapters One and Two distinguish between neo-classical and behavioral economic theory by identifying the apparent differences in their assumptions about maximizing behavior. But a closer examination of the behavioralist position indicates that this distinction centered on maximization may be inappropriate and perhaps not even the relevant and important issue.

The two assumptions common to theories of market economies cited at the start of Chapter One are that: 1) people make choices that are intended to have favorable impacts on their self-interests; and 2) that people are rational. The third assumption offered to distinguish neo-

classical theory is that people choose courses of action that lead to a maximum level of utility (or profits). This particular distinction may be artificial because all three of these assumptions can be summarized into one reasonable statement that both neo-classicists and behavioralists could probably agree upon: "people are, for the most part, doing their best to get the best possible situation for themselves".

Assuming that this statement is an accurate representation of the intuitive root of the maximization assumption, the distinction between the neo-classicists and the behavioralists really centers on the way these two schools define: 1) the means and procedures that a person is assumed to utilize in order to get their best or desired outcome; and 2) the types of outcomes that a person desires, the outcomes that they would consider "best".

The assumption that people are seeking to get the best they can explains nothing without also defining how people decide what the best is and how they go about getting it. For example, a person has before them two choices, 1 and 2. You cannot predict their choice by saying that they will make the selection that will give them the best possible outcome, or that will maximize their utility. More information is needed on how they perceive 1 and 2, and how they might value these different choices. And you have essentially explained nothing if, after they have selected

2, you say that they selected it in order to maximize their utility, that they were seeking to get the best they could.

Such a contention amounts to no more than saying that people do what they do because they do it. Yes, of course, we know that they do "it", that they are "seeking the best", but what we need to know is how they go about seeking the best and what defines as best the particular outcomes being sought. Not only is the contention that people do it because they do it incorrect, it is also not meaningful because it tells us nothing at all about what actually happened and why.

Neo-classical market/price theory does not sat that "people do it because they do it", although some arguments defending the maximization assumption adopt this type of logic¹⁸. Neo-classical theory would be useless if it did so. On the contrary, the theory defines peoples' goals and their abilities to pursue them simply enough to allow maximizing or best seeking behavior in a competitive economy to result in the familiar condition of equilibrium. As a result, under these assumed conditions the theory has a great deal to say about likely aggregate market reactions to changes in costs, supply, incomes and numerous other factors. The theory and its implications are generally consistent with the observed phenomenon of consumers wanting to purchase less in aggregate as prices rise and producers wanting to produce more (and vice versa).

Neo-classical theory's predictive capabilities may be due, in part, to consumer and producer SOP's that include enough neo-classical price response characteristics to make aggregate, average supply and demand curves behave neo-classically. But for explaining and predicting an individual's decision process, or how they will act as individuals in their own unique production and consumption circumstances, the theory loses a great deal of its relevance. For even though under these circumstances people are likely doing their best to get the best they can for themselves, what really matters are the factors determining the best that the person can do and the person's goals.

Cyert and March clearly share this same view in the passage from their book cited above in Chapter Five. The crucial points they make are that:

"... many of the attacks on the (neo-classical) theory of the firm are not so much proper critiques of existing theory as they are suggestions for the development of a theory appropriate to a different set of questions."

and that:

"... we should distinguish between a theory of micro-behavior, on the one hand, and the micro-assumptions appropriate to a theory of aggregate economic behavior on the other." [9, pages 15-16]

As discussed in Chapters Two and Three, the Carnegie school has taken an entirely different approach to studying these factors. Recognizing the cognitive limitations of individuals, and their complex decision environments, the

school has been more interested in developing a theory of individual decision-making processes that can bear up to closer empirical scrutiny than neo-classical theory. This interest has lead them to inquire into what actually happens at the individual's level.

Although a behavioral theory of markets is desired by the Carnegie school, there appears to be no willingness to achieve this by sacrificing a behavioral theory that can explain and predict individual behavior. As a result, behavioral theory has a great deal to offer the study of decision making processes in individual and group situations, but it still has yet to develop a comprehensive and consistent theory of markets and prices.

ENDNOTES

1. This simplified caricature of neo-classical theory ignores some of the other important, and more rigorous, assumptions that permit its use in the analysis of markets. For instance, an assumption is generally made about the degree of homogeneity of the production function. Yet these three assumptions, plus using profits as the proxy for utility, permits a reasonable comparison to a competing view of human economic behavior which follows in the body of the text.

2. See Chapters Two and Three for citations and discussion of the work of Herbert Simon and others from the behavioral school.

3. See Chapter Five, pages 82-83, for a brief discussion of this issue and citations.

4. Milton Friedman's argument, that economic actors only need to behave as if they conformed to these assumptions [cite?, throughout], is often offered in response to Leibenstein's question.

5. The organization of this thesis does not conform to the standard "modernist" structure (ie, Assumptions and Theory, which lead to, Deduction of the Model, Testing of the Model, and a Summary of Results and Policy Implications). The reason for not using the modernist organizational structure (see McCloskey, D.M., *Economical Writing*, V. 24, No. 2 (1985), and by the same author, The Rhetoric of Economics, University of Wisconsin Press, Madison (1985)) is that it would be fundamentally misleading to present these results as such. The intent is to add to the value of this research by bringing some light to the process by which the conclusions were achieved.

6. There is no one style of neo-classical analysis, and over time a number of significantly different styles and approaches have emerged. For example, the industrial organization (I.O.) approach, with its utilization of structure, conduct and performance as its primary analytical framework has developed into a major alternative means of viewing markets and industries.

I.O. analysis is not homogeneous either. A major body of its practitioners, including those like Bain who initiated this type of analysis, view the elements of structure to be limited to conditions of market concentration (analogous to the conditions of competition, monopoly, monopolistically competitive and oligopoly in neo-

classical theory) and view conduct to be essentially limited to the traditionally neo-classicist profit and or utility maximization. As such, this approach to I.O. analysis is clearly neo-classical in its roots.

I.O. has also developed into other areas, including those that are distinctly behavioral, utilizing the flexibility provided by the structure, conduct and performance paradigm to consider factors other than concentration as affecting structure and performance, and considering conduct other than profit maximization.

This discussion is provided to highlight some of the short-comings of the characterization of neo-classicism presented here. Still, this view is not entirely unfair - the emphasis on profit maximization does dominate, particularly when the neo-classicist attempts to econometrically model a market system.

7. The rules of thumb for standard operating procedures discussed in this section are derived from conversations with H. Bucholtz, Dairy Scientist, Michigan State University, and S.B. Nott, Agricultural Economist, Michigan State University, as well as dairy farm managers.

8. From conversations with a farm credit officer.

9. From conversations with Bucholtz.

10. From conversations with Bucholtz.

11. From unpublished data available from the Michigan Dairy Herd Improvement Association, East Lansing, Michigan.

12. From Conversations with Bucholtz.

13. From conversations with Bucholtz.

14. From conversations with Bucholtz.

15. From conversations with Bucholtz.

16. Bucholtz.

17. From conversations with Bucholtz and J.R. Black, Agricultural Economist, Michigan State University.

18. In general, the arguments tend to hold that no matter what people do, no matter what choices they make, they can be seen as maximizers if we take enough of their special circumstances into account. For example, if someone is not maximizing profits, then they are maximizing profits and leisure. And if not these two, then profits, leisure and psychic costs, and on and on. These arguments are basically

saying that if you can identify what it is that people are doing it is possible to find some way to characterize it as maximizing. As Leibenstein points out, all meaning (and usefulness) of the word maximizing is lost if it defines all behaviors. Maximizing means nothing if "non-maximizing" is not permitted to have the opposite meaning. It would seem beneficial to all if these tautological arguments in support of maximizing could be dropped. Economists could then proceed to explore the important and more interesting work of deciding for each of the theoretical problems faced the appropriate set of micro-level behavioral assumptions. (See Leibenstein for further discussion of these issues [18, p494-496].)



APPENDICES

APPENDIX ONE: SYSTEMS DYNAMICS EQUATIONS AND FLOW DIAGRAMS

Systems Dynamics simulation models have three basic types of variables that are used to represent the functions of systems. The first and generally most important are the stock variables (also referred to as state or level variables). The stock variables are the most important variables in a systems model because they represent the portions of the system that are actual conditions or states in the world. All of the other variables serve to change these states, or support the variables defining these changes in states.

Stock variables are the parts of the system that accumulate or decumulate over time. In physical models, the stock variables signify the physical materials that have inertia, that take time in order for their condition to change. A good example from the dairy model is the stock of animals representing the milking herd. Other stock variables in the dairy model might be the stock of feed rations held on the farm, or the stock of farm machinery or the stock of working capital held by the operator in the bank. Stock variables are not limited to representing only physical objects. For example, a person's perceptions of a situation do not change instantaneously, but gradually over time. A stock variable can be used to represent this state of mind.

The variables defining directly how the states change are the rate variables. The rate variable defines how much the stock variables are growing and or decreasing in size over time. In the dairy model examples of important rate variables are "Calves In" and "Calves Out". These variables represent how many calves are entering the stock of calves over time (due to births and or purchases) and how many are leaving (due to maturation or death loss).

The final class of variables is the auxiliaries, which are used to represent information or relationships in the model that do not take any time to change. An auxiliary variable is generally used in conjunction with other auxiliaries and the stock variables to determine what is taking place in the rate variables. An example of auxiliary variables in the dairy model are all of the death loss variables, or the variable keeping constant track of the number of milking animals in the herd (the sum of the stock variables Cows and Young Cows). The time variables are all auxiliary variables that define the length of time it takes for various processes to take place (ie the time it takes to purchase a heifer once the decision has been made to make the purchase).

Figure A1 is a diagram of these three types of variables in a configuration commonly seen in a systems model.

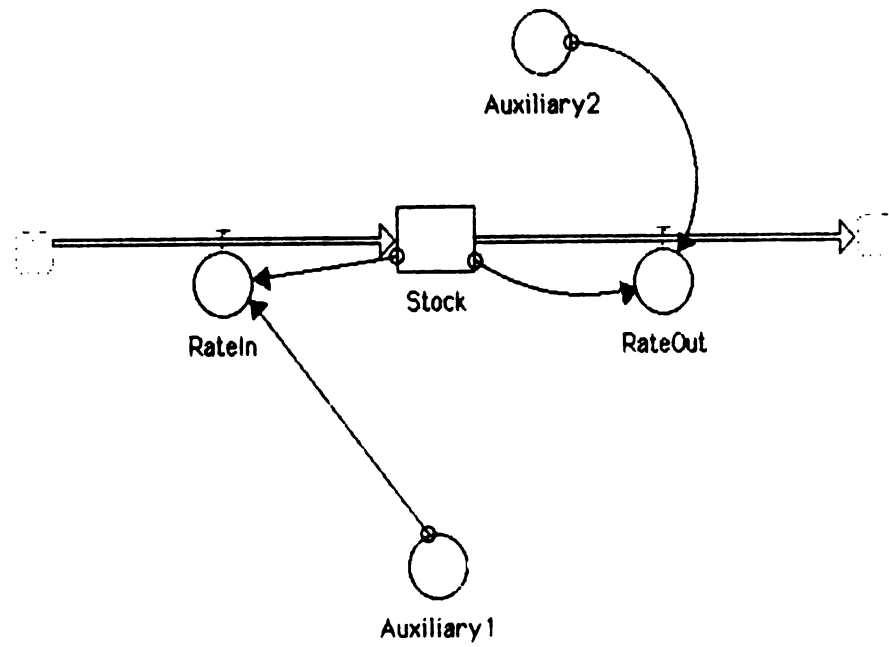


Figure A1: The three classes of variables in a systems model

DEFINITIONS OF THE VARIABLES IN THE MODEL

State Variables:

CALVES: Animals from age 0 to 4 months.

COWS: Milking animals that have freshened a second time.

DMGR-AVG: Desired milker gap ratio, average; a state variable that serves as the source of feedback for the system, and is used to adjust the DESIRED MILKERS goal.

HEIFERS: Animals of age 5 to 27 months.

Y-CW-PURCHASES: Young cow purchases; a state variable that represents the purchases by the operator of young milking animals to make up for any shortage of milking animals, as defined by the desired milker gap (DES-MILKER-GAP). This variable may or may not be used in the model, depending on the scenario.

Y-HEIF-PURCHASES: Young heifer purchases; a state variable that represents the purchases by the operator of heifers for replacement to make up for any shortage of these animals, as defined by HEIFERS-NEEDED. This variable may or may not be used in the model, depending on the scenario.

YOUNG-COWS: Milking animals who have only freshened once, and are in the first lactation.

Rate and Auxiliary Variables:

B-CALF-RATE: Bull calf rate, where half of all of the calves born are assumed to be males.

BIRTH-RATE: The rate at which calves are born. It is assumed that a cow, young cow or heifer will have one calf every 13 months.

CALVES-FOR-REPLACEMENT: The calves that are available to serve as replacements to the milking herd.

CALVES-IN: A rate variable defining the rate at which calves are being born.

CALVES-NEEDED: The number of calves that are needed by the operation simply to maintain the herd at a steady state size, given the assumed death losses from cows, young cows and heifers.

CALVES-OUT: A rate variable defining the rate at which calves leave the calf stage and become heifers.

COWS-CULLED: A rate variable defining the rate at which cows are culled from the herd.

CULL-RATE-STANDARD-COWS: The rate at which cows are removed from the herd due to their reaching the assumed age beyond which milk production declines.

CULL-RATE-STANDARD-Y-COW: The rate at which young cows are removed from the herd due to assumed standard death losses.

CULL-RATE-VARIABLE-COWS: The number of cows to be culled in excess of the standard rate, the number being given any excess milking animals.

DEATH-LOSS-CALVES: The assumed standard rate at which calves die due to disease, illness or other health problems.

DEATH-LOSS-COWS: The assumed standard rate at which cows die due to disease, illness or other health problems.

DEATH-LOSS-HEIFERS: The assumed standard rate at which heifers die due to disease, illness or other health problems.

DEATH-LOSS-Y-COW: The assumed standard rate at which young cows die due to disease, illness or other health problems.

DESIRED-MILKERS: The number of milking animals that the operator desires for the farm.

DESIRED-MILKER-GAP: The difference between the current number of milkers and that number desired by the operator.

DES-Y-HEIF-GAP: The difference between the number of heifers available for replacement and that number needed by the operation to maintain the herd at a steady state size.

DMG-RATIO: A ratio between DES-MILKER-GAP and DESIRED-MILKERS, used to adjust the state variable, DMGR-AVG (see above).

HEIFERS-F-REPLACEMENT: The number of heifers available to serve as replacement animals for the herd.

HEIFERS-IN: A rate variable defining the rate at which calves are entering the heifer stage.

HEIFERS-NEEDED: The number of heifers needed to maintain

the herd at a steady state, given the standard assumed death losses and cull rates of milkers.

HEIFERS-OUT: The rate at which heifers leave the heifers stage to become either young cows, or are lost due to death.

MAT-RATE-CALVES: The rate at which calves are assumed to mature and reach the heifer stage.

MAT-RATE-HEIFERS: The rate at which heifers are assumed to mature and reach the young cow stage.

MAT-RATE-Y-COWS: The rate at which young cows are assumed to mature and reach the cow stage.

MILKERS: The number of milking animals (cows + young cows).

RETE-RATE-STEADY-STATE: The steady state retention rate used to calculate CALVES-NEEDED and HEIFERS-NEEDED.

SALE-B-CALVES: The number of bull calves sold.

SALE-CULL-COWS: The number of cull cows sold.

SALE-H-CALVES: The number of heifer calves sold (that number in excess of those needed for replacements).

SALE-Y-COWS: The sale of young cows (those in excess of the number needed for replacements).

SOP-Y-COW-PUR: An SOP defining the monthly purchases of young cows. The variable may or may not be used in the model, depending on the scenario.

TIME-AVG-DMGR: The assumed number of months over which the moving average for the desired milker gap ratio is calculated.

TIME-PUR-Y-CW: The time it takes the farmer to purchase young cows once the decision has been made to make the purchase. The value of this variable changes depending on the scenario.

TIME-PUR-Y-HEIF: The time it takes the farmer to purchase heifers once the decision to make the purchase has been made.

Y-CW-PUR-DES: Young cow purchases, desired; the number of young cow purchases the farmer would like to make.

Y-CW-PUR-GAP: The difference between the number of young

cow purchases the farmer desires and the number of purchase the farmer is currently in the process of completing.

Y-CW-PUR-IN: A rate variable defining the rate at which the purchases of young cows occurs.

Y-HEIFERS-AVAILABLE: The number of calves that are actually used as replacement animals and entered into the heifer stage.

Y-HEIF-PUR-DES: The number of young heifers the farmer would like to purchase.

Y-HEIF-PUR-GAP: The difference between the number of heifers the farmer would like to purchase and the number that the farmer is currently in the process of purchasing.

Y-HEIF-PUR-IN: A rate variable defining the number of heifer purchases the farmer will commence each month.

YOUNG-COWS-CULLED: A rate variable defining the rate at which young cows leave the herd, due to death loss.

YOUNG-COWS-IN: A rate variable defining the rate at which heifers are entering the young cow stage.

YOUNG-COWS-TO-HERD: A rate variable defining the rate at which young cows are leaving the young cow stage and entering the cow stage.

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