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A study of the farm management process in relation to modern operations research technology

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A STUDY OF THE FARM MANAGEMENT PROCESS IN RELATION TO MODERN OPERATIONS RESEARCH TECHNOLOGY

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INTRODUCTION

The value of any mental concept is determined by its usefulness in aiding thought processes regarding certain elements of our environment. As the environment changes, so too must the mental conceptualization of it. In this way the recent development of the electronic computer and the increasing demands which are placed upon the managerial capacity of farmers seem to warrant a revision of the traditional concepts of the farm management process.

There is another, indirect, value to deriving a concept from some basic principles in this way, however. This is due to the way in which such a procedure provides a new approach to the problem at hand and suggests many new and interesting insights into it. Some such insights provided by the concepts we discuss in the earlier chapters form the subject matter of later chapters.

The formal discussion is initiated in Chapter 2 by considering the implications of economic development and resulting innovations for the farmer; in particular, the growing demand by farmers for assistance in their organization duties is noted.

In Chapter 3 we consider some previous classifications of the farm management process. Implications from control theory and computer simulations of the human problem solving process are then utilized together with some more intuitive ideas to revise the classical normative assumptions and formulate a more behavioral concept of the farm management process.

The importance of problem solving activity in the farm management process then leads us to consider this in more detail in Chapter 4 where use is made of analogies between the workings of the human mind and the modern digital computer. The processes of recognizing, defining and solving problems are considered a useful classification of the problem solving process and, finally, some consideration is given to the effects upon these processes of problems which defy a clear-cut definition.

In Chapter 5 we consider the elements which seem to be common to all problem situations and we combine the work of psychologists, on the one hand, and economists, on the other hand, to develop a generalized model of a dynamic problem situation. A distinction is made between the ways in which farmers and economists seem to conceptualize problems and attempt to solve the overall economic problem facing the farmer.

A brief consideration of the complicated effects of imperfect information is given in Chapter 6 together with some consideration of the converse simplifying effects of the assumption of certainty (perfect knowledge).

We then go on to consider more fully the hierarchical nature of the farmer's interpretation of the problem situation he faces. Also, we consider some reasons for its existence and some advantages to be gained from it.

In Chapter 8 we consider some of the implications of the farmer's mental construct and how it relates to our concept of the problem solving process.

Chapter 9 is given to considering the general form of the mathematical programming model and its interpretations and solution. The special case of linear programming is given particular attention.

The next three chapters consider the uses and relevance of operations research procedures in assisting the processes of recognizing, defining and solving problems. Some detail is given in Chapter 11 of how the normal linear programming procedures can be interpreted in this light.

The concepts developed allow us to conceptualize the characteristics of ill-defined problems more clearly in Chapter 12.

In Chapter 13 we consider briefly the processes underlying the quantification of a model and note the potential for electronic data processing in this field.

We end the main part of the discussion in Chapter 14 by giving a more detailed description of work which has been done towards relating models in the characteristic hierarchical structure utilized by farmers' mental processes. Consideration is given to reasons why this appears to be a fertile area for further study.

The concluding chapters, 15 and 16, are given to considering the more interesting concepts derived in the discussion and their implications for agricultural extension, then summarizing the discussion retrospectively.

GENERAL ECONOMIC BACKGROUND

When considering entrepreneurial activity in general it has been common for economists to distinguish between two types of activity, namely, organization and supervision.

The managerial activity referred to as organization is the selection of the firm's goals, formulation of possible plans, selection of a plan to be followed and analysis of the results, etc. In general, we might say that organization is the activity which results in choice of a particular plan of action.

Supervision, on the other hand, is the managerial activity required after the plan has been chosen and it is desired to put it into effect. Thus, we might consider formulation of the daily work plan and adjustments to the overall plan of action necessitated by unforeseeable variables such as the weather or machinery breakdowns.

It will be clear that the supervision activity also calls for evaluations and decisions and, hence, the distinction between the two is ill-defined and the dividing line between the two may be shifted in either direction according to individual interpretation. In large industrial enterprises the distinction seems to be relatively well defined whereas in agriculture both activities are normally carried out by the farmer.

The relevance of the distinction for the purposes of this thesis is due to the changes in these two areas of activity which are resulting from the economic development now being experienced in some countries.

Under conditions of subsistence agriculture supervision tends to be by far the more important activity. The production pattern is fixed by tradition and changes only very slowly over a long period of time by means of trial and error and processes of natural selection. Very little change is encountered from year to year, except perhaps in the weather and other natural phenomena, and the farmer carries on following similar plans from year to year. Also most families are self-sufficient in all their needs and the activities of each family are relatively independent of the lives of the other families in the community.

The Effects of Economic Development

The process of economic development, however, seems to be synonymous with the generation of new knowledge and specialization of duties of individuals within the community. Economic development stems from a long chain of cause and effect relationships which are at best poorly understood. And in any case the path followed by the economic development will be determined by the cultural values and reactions to change of the individuals within the community. However, one of the initial steps is often the change from a subsistent and self-sufficient economy to one of a market economy. This allows individuals to specialize in different directions of entrepreneurial activity and allows advantage to be taken from the greater productive efficiency possible. (This greater productive efficiency is the force motivating the specialization). However, this specialization, while allowing the benefits of greater productive efficiency, also results in greater interdependence between the members of the community. For example, initially the blacksmith will become dependent upon the farmer for his food and the farmer will become dependent upon the blacksmith for shoeing his horses and mending his ploughs. Characteristically we find that this procedure continues with economic development until, in such countries as the United States of America, a large proportion of farm inputs are purchased from the non-agricultural sector. For example, American farmers now buy large quantities of fertilizer, herbicides, insecticides and machinery from the non-agricultural sector and many processes such as butter and cheese making are no longer carried out on the farms. This specialization, together with the increased productivity it facilitates, will also allow the generation of new technology which also causes greater interdependence. For example, farmers come to rely upon the supply of fertilizers and herbicides, etc., which were not available previously. Also, the techniques of farming become more developed and specialized and the members of the non-agricultural community expect a higher degree of processing and quality in the products they buy.

Thus the farmer is no longer a 'Jack of all trades.' He has become a more and more specialized operator.

The Economic Forces Underlying Specialization

It will be useful at this point to consider the economic forces determining the degree of specialization which occurs.

We can consider the classical form of the production function as shown in Figure 1 where the output Y is related to the level of input of X_1 in the manner illustrated with the level of input of all other resources being held constant. We might write this as:

$$Y = f\ (X_1 \mid X_2, X_3 \ldots\ldots\ldots, X_n)$$

The curve illustrated indicates an area of first increasing and then decreasing returns to the level of resource use. We can next consider the product transformation curve which can be interpreted as the use of fixed levels of the resource X in the production of varying ratios of outputs Y and Z (Figure 2).

$$Y = f_1\ (X_1 \mid X_2, X_3, \ldots\ldots., X_n)$$

$$Z = f_2\ (Y_1 \mid Y_2, Y_3, \ldots\ldots., Y_n)$$

If $X_1 + Y_1$ = constant, we can write

$Y = G\ (Z)$ where G is the product transformation function. If we consider that we have some criterion such as price, profit, etc., for comparing the rates of return from the two directions of production, we can draw this into the diagram as shown by the straight lines.

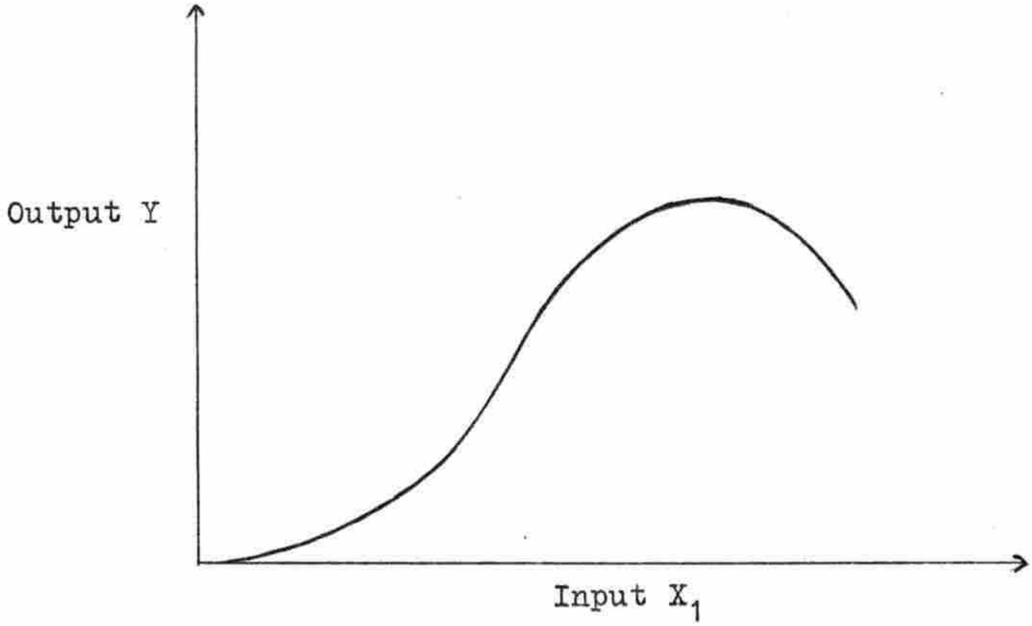

Figure 1. 'Classical' production function

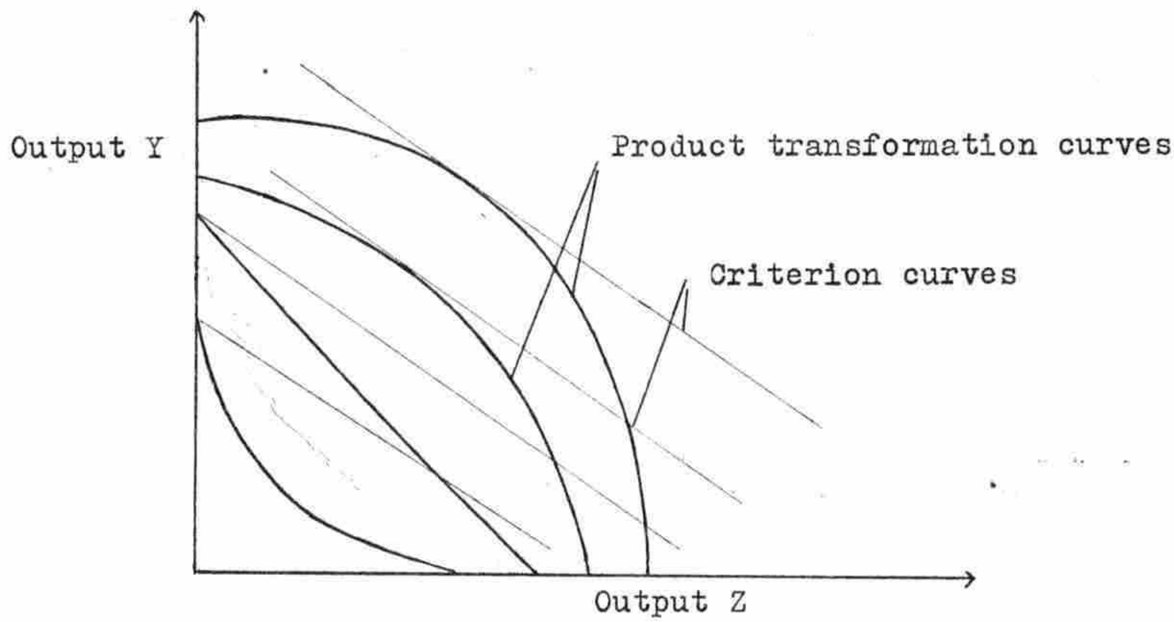

Figure 2. Product transformation and criterion functions

Applying classical marginal analysis then tells us that, if the production possibility curve is concave to the origin, the 'highest' level of the criterion function is attained where the production possibility curve is tangent to the criterion curve. Thus, a <u>combination</u> of outputs Y and Z is the most 'profitable.'

We can see that, assuming the classical input-output relationship already illustrated, the level of resource availability may have an important effect on the level of specialization which should occur. However, assuming only one resource is obviously very unrealistic; so, we will consider the interaction of several production possibility curves, one for each resource.

Figure 3 illustrates the situation and shows how, in this case, the most profitable mix of outputs Y and Z will be Y^1 and Z^1.

Now let us assume that the production possibility curve which is convex to the origin corresponds to the limited managerial capacity or managerial 'restraint' of the entrepreneur[a] and that the other two curves refer to the quantities of land and capital which the entrepreneur controls. We can then visualize that as economic development occurs, the quantities of resources such as land and capital which the entrepreneur controls, will increase. This will result in a gradual 'relief' of the land

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[a]We could develop the same results if we assumed it was linear or even concave to the origin if the criterion function were even more concave.

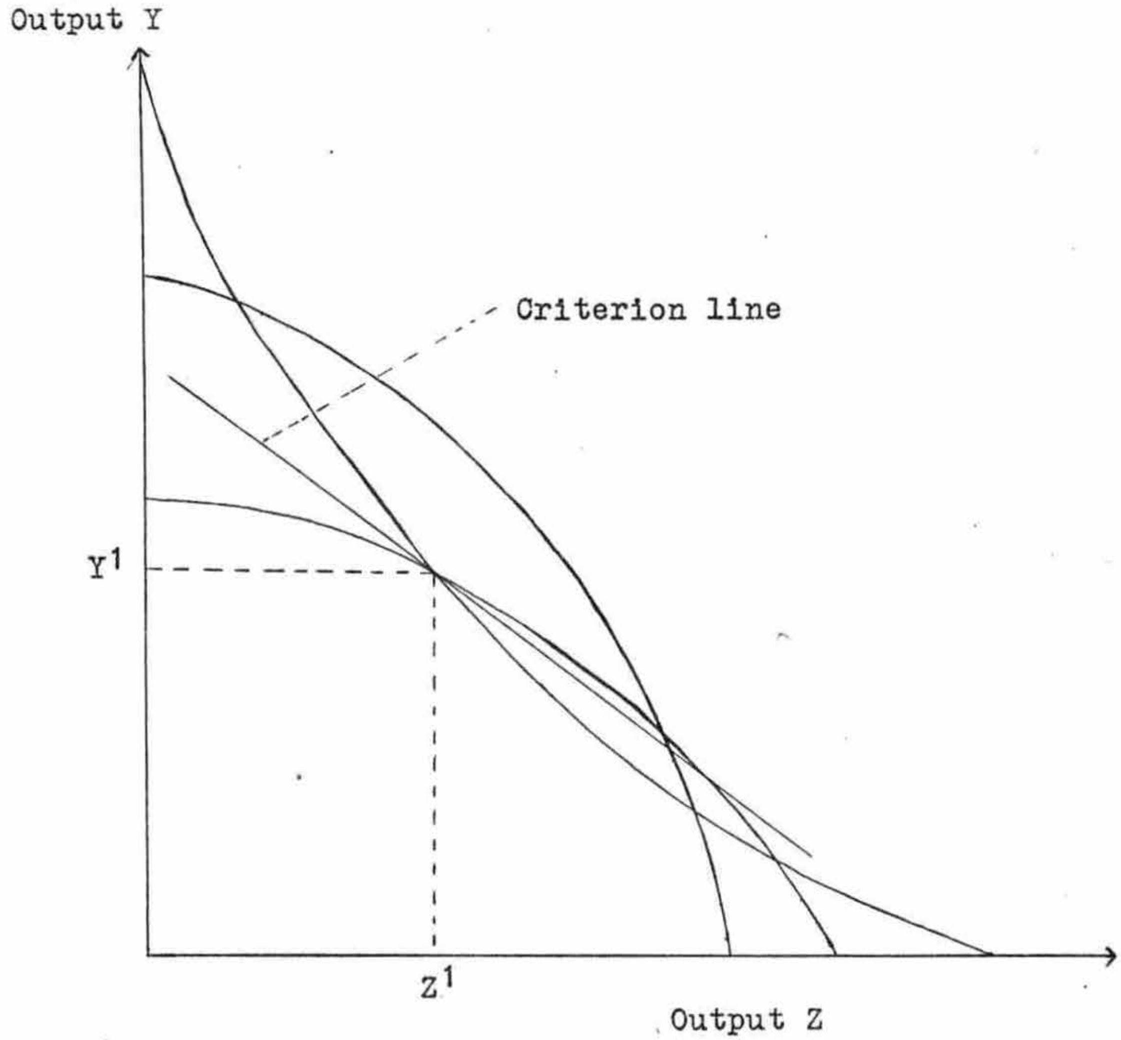

Figure 3. The interaction of several production possibility curves

and capital 'restraints' and the two corresponding production possibility curves will 'move away' from the origin. The managerial restraint will become the more important one and because of its shape greater specialization will be profitable. Two different entrepreneurs with different aptitudes and experiences will have different managerial production possibility curves. Hence, the first might find it more 'profitable' to specialize in production of product Y and the second, in production of product Z.

This result will also be encouraged by the fact that as economic development occurs new knowledge is generated, technologies become more sophisticated, and again the managerial constraint is emphasized.

Economic development may also result in higher entrepreneurial income and in the entrepreneur wishing to devote more of his time to leisure activities, again adding emphasis to the managerial restraint.

On the other hand, however, it may become possible to educate the entrepreneur better and this may have the effect of relieving the managerial restraint to some extent.

It should be noted that if the criterion function is not a straight line as we have assumed (i.e., if the entrepreneur has a preference for specialization or diversification), this will affect the degree of specialization also.

Historically, we may say that specialization has occurred to a very great extent and there seems little reason why this trend should not continue.

The Implications of Economic Development and Specialization

We should notice that the change from subsistence agriculture to a developed agriculture with greater specialization has caused greater interdependence between the members of the community and has resulted in a high rate of technological change. These two factors together result in greater changes in prices, values and techniques, etc., taking place which mean that the organizational part of a farmer's duties are considerably increased and may be expected to increase as economic development continues.

If the managerial capacity of the farmer is a limiting factor on the income he can derive from his other resources, we can impute a value to it. Also, we know from classical theory that if the farmer wishes to increase his income above the level to which his managerial capacity limits him, then it will be advantageous for him to increase his managerial capacity until the marginal cost of the increase is equal to its imputed 'shadow' value. This may well mean that it will be to his advantage to hire the services of someone to assist in his managerial duties.

These inferences form the basic motivation for this thesis and the distinction which was made earlier between organization and supervision in entrepreneurial activity as well.

Recent results of economic development in the United States in particular, have resulted in the generation of many new managerial aids. These have become known as operations research (O.R.) techniques and they rely heavily upon another development, that of the high speed electronic computer.

These new methods form a very complex and specialized aberration of managerial activity. They do have a high productivity in certain situations but their application to practical problems requires considerable specialized training. However, it would seem that if the forces of economic development do tend to emphasize the importance of the managerial restraint as we have suggested above, and if these operations research methods do have a high productivity in aiding the managerial process, then it would seem to follow as a natural implication of these results that it will be to the advantage of many farmers to hire the services of an O.R. specialist to help with their managerial duties.

If the value of these new methods is not as great as we have assumed, however, a farmer might prefer to employ a supervisor, commonly called a 'foreman' or 'right-hand-man.' This possibility is by no means new but to carry out his duties efficiently, the supervisor needs to be available 'on the spot', full-time to make small, quick decisions. On many large farms this alternative has been followed but to the average family farm the employment of a full-time foreman is uneconomic. For this reason and because it is not new, we will tend to ignore this possibility and consider only the possibility of employing the organization specialist, and mainly on a part-time basis. This would allow the farmer to concentrate on the task of supervision and would facilitate the application of any of the new organization methods which prove valuable, via the specialist's knowledge. Also, it is worth noting that most of the new operations research methods which seem to have immediate potential for application to agriculture seem to be classifiable as organizational rather than supervisory aids.

A CONCEPTUALIZATION OF THE MANAGEMENT PROCESS

The objective of this chapter will be to formulate a concept of the managerial process in agriculture which will be of use not only as a useful mental construct but also later when we wish to consider certain aspects of the process in more detail.

As already mentioned, we can consider the duties of management as consisting of supervision activities and organization activities. In order to agree with the current nomenclature of the literature on the subject, we will consider the term 'management' as roughly equivalent to 'coordination.' Thus, our definition includes more than just decision-making as in Simon's definition (1, p. 2), and it includes more than just organizaion as we have defined it.

Previous Classifications

Heady (2, p. 466) has emphasized, as we have already seen, that "the need for management arises out of the dynamic conditions of change or variability of price and production quantities which can only be estimated subjectively for the future."

He thus observes that the fundamental roles of management are to:

1. Formulate expectations of the conditions which will prevail in the future.
2. Formulate a plan of production (or investment) which is logical and consistent with expectations.
3. Put the plan of action into effect.

4. Accept responsibility for the economic consequences of the plans.

Johnson and Haver (3, p. 8) classify the fundamental roles of management as follows:

1. To observe those factors which effect his business environment.

2. To analyze the data so obtained.

3. To decide on a course of action indicated to him by this analysis.

4. To act on this decision and put the course of action into effect.

5. To accept responsibility for the consequences following this course of action.

They enumerated five fields which are liable to change and, hence must be studied by the farmer.

1. Prices.

2. Production methods and responses.

3. Potential technological changes.

4. The personalities of people directly and indirectly involved in their business activities.

5. The general political situation.

A similar classification has been followed by Bradford and Johnson (4, p. 7).

Simon (1, p. 2) considers the management process as roughly equivalent to the decision-making process. Thus, he considers only a subset of the managers' duties as we have classified them but he enumerates three types of activity for decision making.

1. Intelligence activity

2. Design activity

3. Choice activity

Intelligence activity is interpreted, using the military use of the word intelligence, to be the process of observing and searching for conditions calling for decisions.

Design activity refers to the process of inventing, developing and analyzing possible courses of action.

Choice activity is the process of selecting a particular course of action from those available.

He also distinguishes between two polar types of decisions, 'programmed decisions' and 'nonprogrammed decisions.' Decisions are 'programmed' to the extent that they are repetitive and routine and that a definite procedure has been evolved for handling them. They are 'nonprogrammed' to the extent that they are novel, unstructured and consequential. No well-defined method for handling them is available in a routine way.

Nielson (5) has classified the management process as consisting of the following eight categories:

1. Formulation of the goals or objectives of the firm or unit.
2. Recognition and definition of a problem or recognition of an opportunity.
3. Obtaining information - observation of the relevant facts.
4. Specification of and analysis of alternatives.
5. Decision making - choosing an alternative.
6. Taking action - implementation of the alternative selected.

7. Bearing responsibility for the decision or action taken.

8. Evaluating the outcome.

He points out that these steps need not be followed strictly in this order. The farmer is able to jump from one to another. Nielson considers that for the farm as a whole, the steps are all, more or less, continuous processes.

Nielson's classification is somewhat different from the other classifications in that it is somewhat more descriptive and less normative. And he contends that empirical research, such as the Midwest Farm Management Survey (6), does imply that farmers carry out most of these processes. However, any normative or descriptive study of the managerial process comes up against the problem of defining the goals, objectives, or preferences of individual human beings. These are always highly individual and make it very hard to deal with individual farms under the framework of any general model. For these reasons, it is hard to verify the appropriateness of any particular classifications. It was probably in an attempt to avoid some of these difficulties that most of the models proposed by economists have assumed the classical normative model of an economic man who is rational, has considerable knowledge, a well-organized and stable system of preferences at least in ordinal terms, and chooses to maximize something (profits, utility, etc.) However, more modern developments from behavioral science, economics and psychology raise considerable doubts regarding many of these assumptions and suggest more appropriate ones.

It is often not the case that farmers wish to maximize profits and it is questionable whether farmers do try to maximize anything.[a] It is also important to remember the limitations on man's behavior which are imposed by his limited access to information and his limited abilities to perceive, process and analyze information (10).

Nielson's treatment of the managerial process draws heavily upon theoretical and empirical work in psychology and recognizes that farmers may have multiple and shifting goals and multiple and shifting means for attaining goals; also, that the recognition of a problem is an important and elementary function of the manager. We will see the importance of these concepts in a behavioral model of the management process later.

Cybernetics and the Farm Firm

The reader may have noticed that all the classifications of the managerial process which we included in the last section referred to the importance of observing the environment around the farmer and using this information to derive a plan of action, Hence, we can see that a large part of the farmer's duties in carrying out the managerial process may be dealt with best in terms of an information-processing model. The consideration of information-processing leads us to consideration

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[a]Except perhaps such vague entities as 'satisfaction' or 'utility' over some time period.

of a relatively new academic field often referred to as 'Control Theory' or, to give it the name coined for it by Wiener, Cybernetics. We will now give a brief consideration of some of the elements of this new discipline as they apply to the situation existing on the typical family farm.

We will hereafter refer to the process of collecting information, analyzing it and deriving a plan of action as that of problem solving. As we have noted above, problem solving is undoubtedly one of the most crucial processes included under the heading of farm management.

There is often much discussion among economists and agriculturalists about the differences which exist between farming businesses and industrial businesses. However, if we consider either type of business as an information processing organization, we find that not only are the two organizations very similar, but they share many of these similarities with other organizations such as machines in an automatic factory or cells in a living organism. It is these similarities or generalizations which form the subject matter of Cybernetics.

One of the first and most classical publications on Cybernetics was a book by Wiener (7) published in 1948. The reader is also referred to (8, p. 96) and (9, p. 76) for simple, brief discussions of the topic. The basic premises are that the essential processes in the functioning of any organism are information transfer or 'communication' and control. From this, it follows that all the components of an organization work together in a communications network. And, they operate in this manner to reach or maintain an external goal (or its goal image within the organization). The concept of a goal is an important one. A goal is defined to be that object or event which the behavior of an organization operates to reach or maintain. If the behavior of an organization is not orientated towards the achievement or maintenance of some goal, it is said to be purposeless. That is, we do not need to argue about the presence or absence of a goal. The answer to its existence lies in whether or not we can regard the behavior of an organization as directed towards the achievement or maintenance of some object or event.

Goals may be simple or complex and an organization may have a whole set of simple and complex goals. We will now utilize the degree of complexity of these goals and their mode of use by the organization as a criterion to use in ranking the organization. This ranking will reflect the ability of the organization to use information and 'make up its own mind.' We will progress from a consideration of the most elementary organizations to the simple goal maintaining systems, then to the automatic goal changing unit, and finally to the reflective goal changing units.

First, we can consider the two types of elementary organization - the transformation unit and the sorter.

The transformation unit (Figure 4) is directed continuously from an external source and can find no goal of its own. An

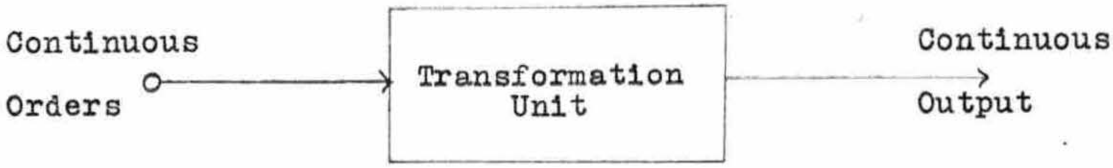

Figure 4. A simple transformation unit

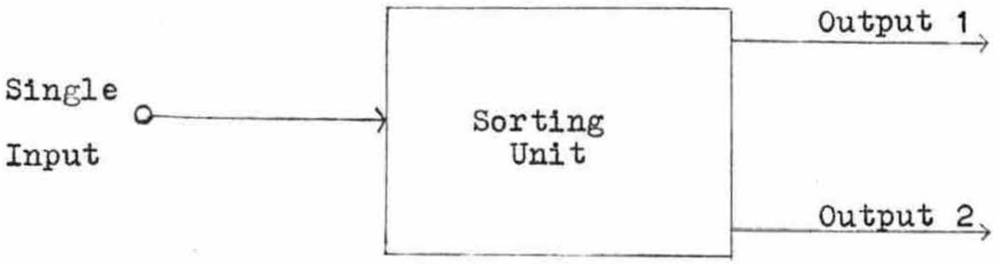

Figure 5. A simple sorting unit

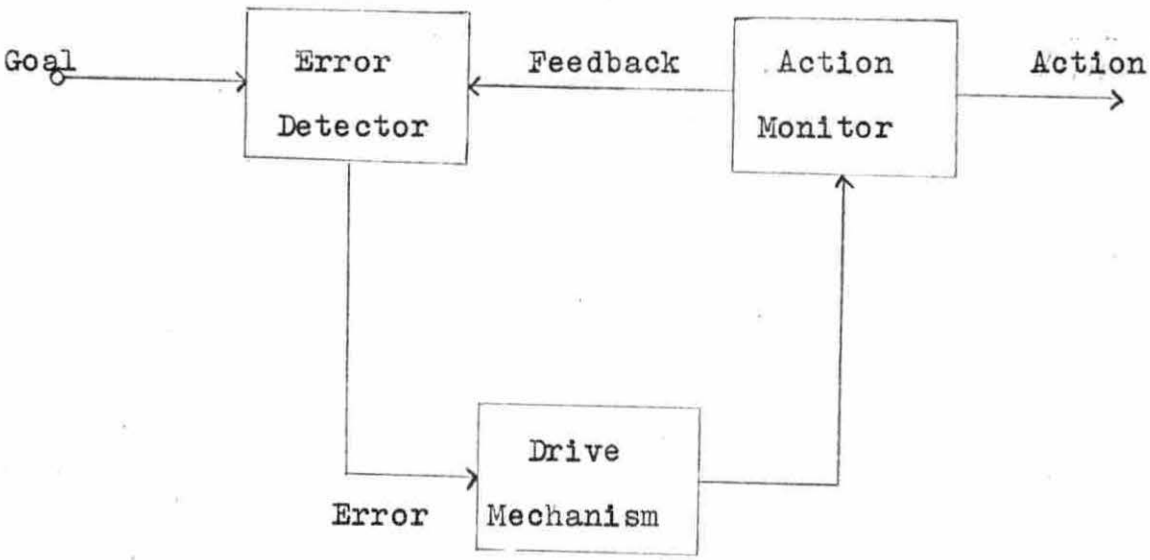

Figure 6. A simple negative feedback circuit

example is a gear train. It performs the three functions of reception, conduction (or transformation) and output transmission. A continuous sequence of goals result in a continuous stream of output.

The sorter (Figure 5) is somewhat like the transformation unit in that it has to be fed continuously, but it can perform simple search and recognition operations common to more complicated processes. An example is a gravel sorter. The rules for sorting (or decision) are built into the unit.

A slightly more complicated organization is the simple goal maintaining unit. This is one of the simplest organizations which can control its actions towards the maintenance of a goal. The crucial element of this simple organization which allows it to control its own operation is the presence of a feedback-loop. This feedback-loop allows the unit to monitor its own operation and compare this with its goal. In this way it can detect error between its own operation and its goal and hence, it can take action to reduce the error and thereby maintain its goal. Figure 6 shows this situation diagramatically. An example of this type of unit is the governor on a steam engine.

It is important to notice that purposeful control is impossible without some form of feedback. And since, by definition, the achievement or maintenance of a goal is impossible without purposeful or 'goal-directed' control, it follows that feedback and control are essential for the organization to achieve or maintain its goal(s).

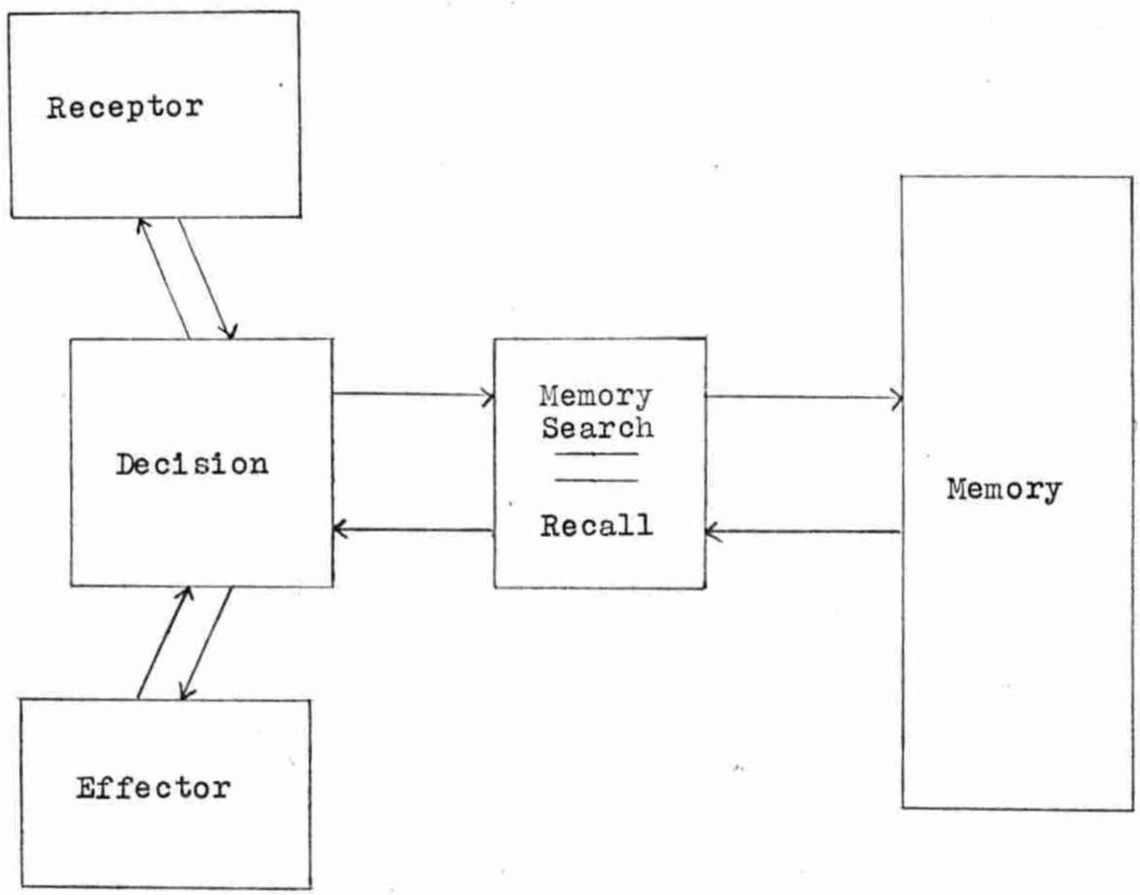

Figure 7. Feedback circuit with memory device

The three elements, transformation units, sorting units and feedback are the basic elements from which more complex and more versatile organizations can be built.

The next type of organization which we wish to consider as we proceed up our 'scale of complexity' is the automatic-goal changing unit. This is but one of the many organizations which can be derived from the three basic elements considered above. This organization (Figure 7) has several alternatives prepared for action and also has the rules set up for applying one or the other of them when external conditions change. It can predict the best alternative; this prediction requiring a second order feedback system or <u>memory</u>. We could cite the example of a cat that chases a rat - not by following the rat's position at a given time, but by leading the rat's position based on its memory of how rats ran in the past. Another example is a telephone exchange. Thus, the immediate goal of a telephone exchange is to search and find a specific number dialed by a subscriber. Its goals change for each different number that is dialed.

We call such an organization which can control itself and particularly if it can change its goals, an autonomous organization.

The addition of a memory is the crucial element which has allowed this organization to become autonomous. And the larger and more accurate the memory and the faster the recall, the more autonomous the organization can be.

The addition of a memory raises many interesting possibiliities, one of which is <u>learning</u>. Thus, the cat can learn by experience how to predict more closely how the rat will run. The telephone exchange can be rewired to include more numbers.

We can also note that operating with a memory will imply different priorities or values for messages into and out of the memory and for different actions. For example, a telephone exchange receiving several calls at once must decide which to answer first.

Finally, we can consider the 'highest' level of autonomy which contains a third-order feedback system or what is called a <u>consciousness</u>. We will call it a reflective goal-changing unit (Figure 8). Such an organization can collect information, store it in its memory and then reflect upon or examine the contents of the memory for the purpose of formulating new courses of action.

An example of such an organization is not hard to find since it is what we would expect of any business organization or human being. If we imagine someone sitting in a chair considering what he should do next out of the possibilities open to him, we have an example of someone using their reflective goal-changing circuits. Indeed, the average farmer and, hence, the average farm firm are fairly good examples of a relective goal-changing organization.

In the above diagram the dotted lines refer to comparisons of what is going on with what has happened in the past and what might occur in the future, which may be regarded as second and

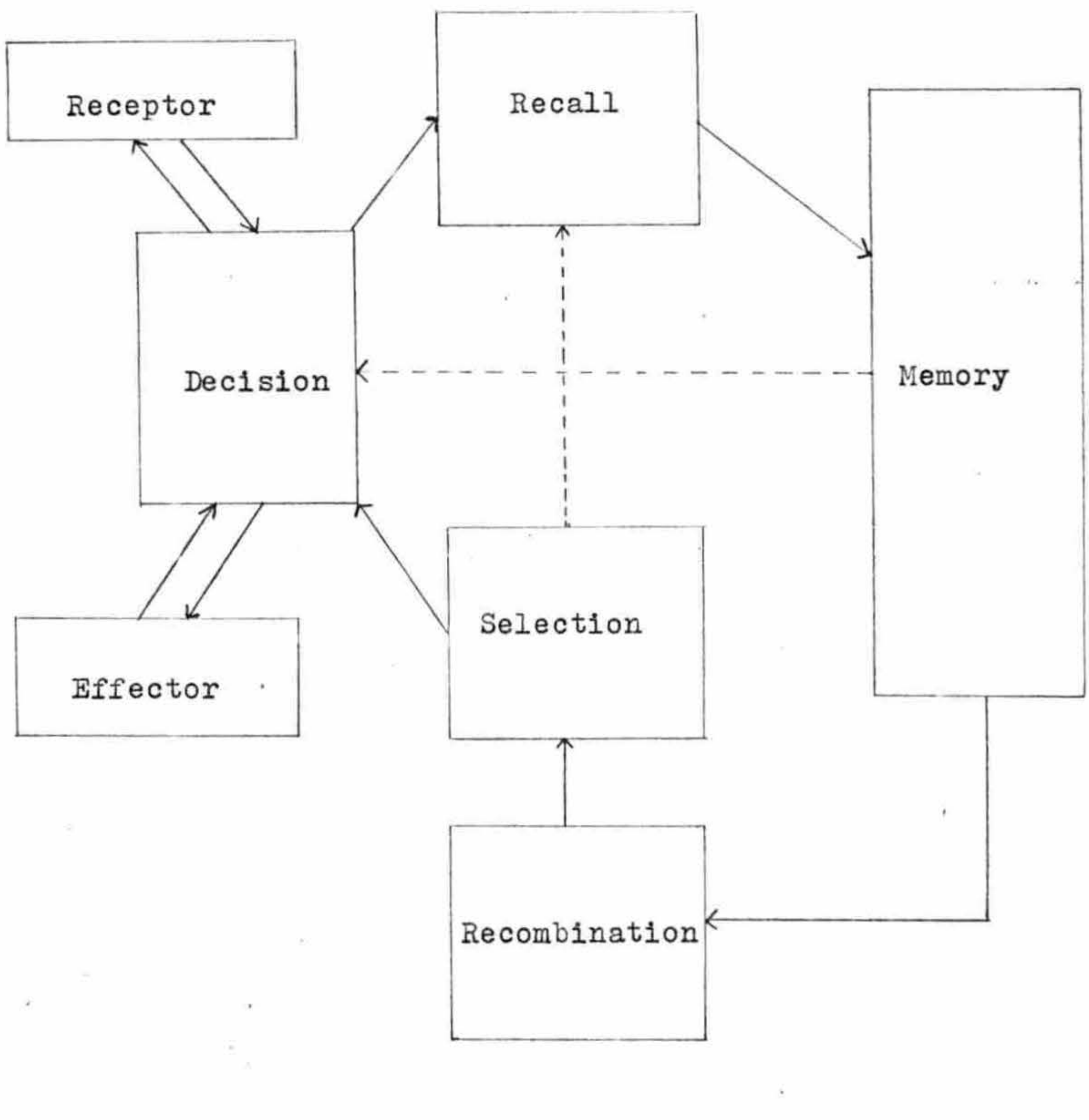

Figure 8. Reflective goal changing unit

third order predictions.

The addition of a consciousness opens up vast new opportunities. For example, learning can be made selective, the attention of the organization can be redirected, the network conditions in an organization may be investigated, the memory can be searched, and the differences between various actions and the goals which direct them perceived. The organization becomes able to direct its own growth and make innovations. It even becomes possible for the organization to replace faulty parts.

Communication and control diagrams along the lines of those illustrated above are useful aids in alalyzing the structure and efficiency of a business and this applies also to farm businesses. Naturally, these diagrams can become very complicated but because of the importance of the processes of communication and control in the operation of an organization, they are very useful. One such generalized diagram (9, p. 86) which summarizes some of the above discussion in terms of the usual business organization is outlined in Figure 9. In terms of a typical farm the farmer functions as both the goal-setter and the controller. The controlled system will naturally be the farm. The uncontrolled disturbing influences will be such things as weather, prices and technological change. The sensors will be the hired laborers or members of the farmer's family who report the state of the farm to the farmer and in this case the farmer, also, may operate as a sensor himself. Other sensors reporting the more external influences to the farmer will be market reports, out-

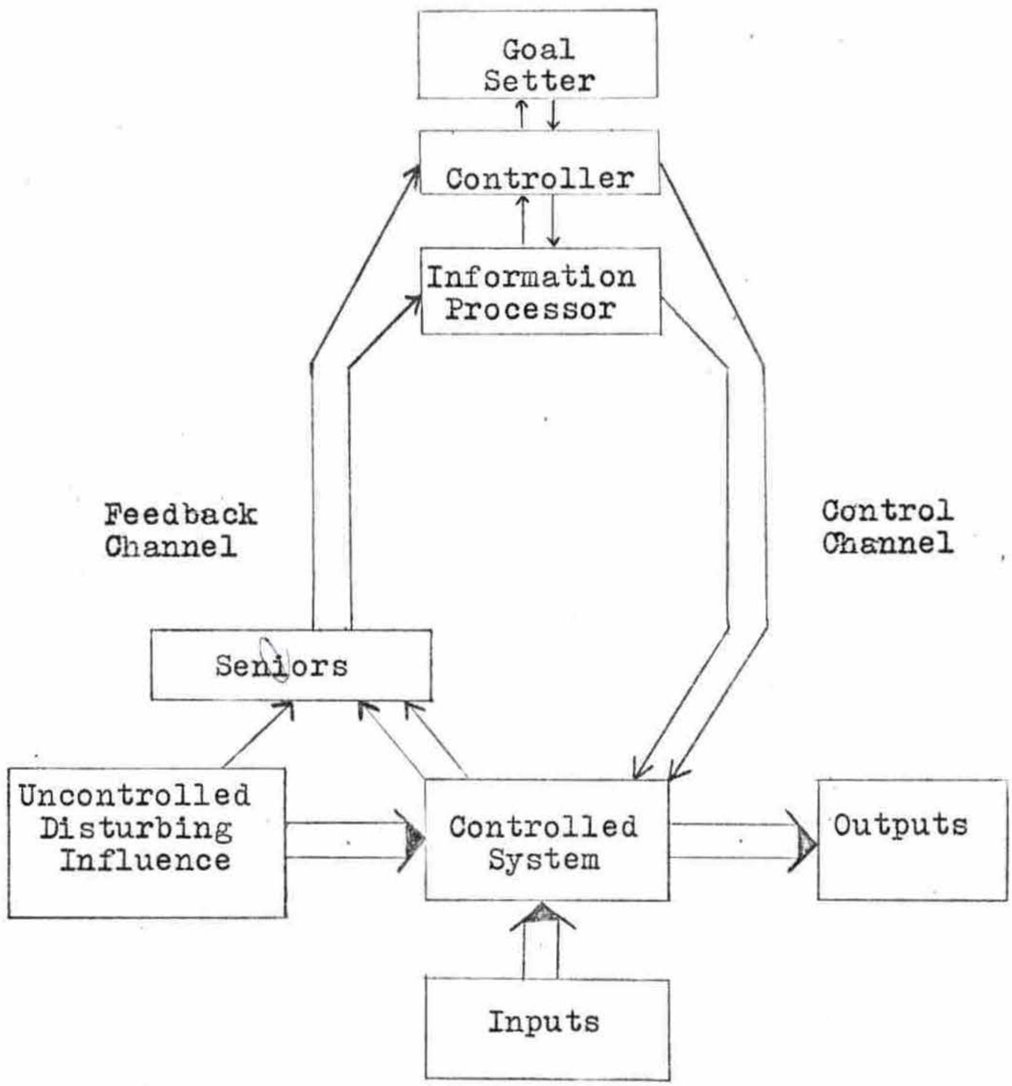

Figure 9. A simplified communication and control diagram of a business organization.

look reports, newspapers, etc. The information processor at the present time is also the farmer; however, one of the objectives of this thesis is to consider the relevance of the new operations research and computer methodology to the duties involved in problem solving (which includes information-processing as we are using the word here) on the farm. We can see clearly here how the need for information processing arises as a consequence of feedback which we have already seen is essential for control. Thus, in terms of the farm, it can be seen that any improvements in information processing which may be possible with the new operations research methods may also result in better control of the farm, i.e., better goal achievement.

We should notice the importance of the goals which apply to the farm. Although the processes of goal setting, controlling, and information processing are all carried out by the farmer, we will see the reason for separating them in the next section when we consider simulations of the human problem solving process.

Before we move on, however, it will be instructive to point out that this system as we have described it is overly simplified; thus, each of the sections which we have been considering could be represented as a similar subsystem. We could regard it as an hierarchical system of subsystems with an hierarchical system of goals. Again, the importance of this observation will be seen more clearly later.

Simulations of the Human Problem Solving Process

We saw in the last section how human beings could be regarded as reflective goal changing organizations and we saw the extreme generality of the processes of feedback and control in purposeful activity. It is not surprising, therefore, that a fair amount of work has recently been done upon examining human problem solving processes in terms of information processing or feedback and control processes.

Newell, Shaw and Simon (11, 12, 13, 14) were among the first to attempt simulations of the human problem solving process using an electronic computer. The results of their work created much interest and has since led to many other simulations of the human mental processes. (See Reitman (15)). But the underlying methodology and rationale for using computers have remained essentially the same as those outlined by Newell, _et al_. The basis of their simulations can be regarded as processes of feedback and control. Thus, they postulated (1, p. 27) that the human problem solving process proceeds by means of 1) erecting goals, 2) detecting differences between present situation and goal, 3) finding in memory or by search, tools or processes that are relevant to reducing differences of these particular kinds, and 4) applying these tools or processes. Thus, each problem generates subproblems with subgoals until a series of subproblems are found which can be solved. The solution of this series of subproblems then solves the overal problem. If the identification of these subproblems seems too intractable as may often occur in practice, the individual may accept an approximation, i.e. a partial solution corresponding to solutions of a subset of the subproblems.

The model of a human being's mental equipment postulated by Newell, _et al_. (11, p. 3) is as follows:

> 1. A control system consisting of a number of _memories_ which contain symbolized information and are interconnected by various ordering relations.
>
> 2. A number of primitive _information processes_ which operate on the information in the memory. Each primitive process is a perfectly definite operation for which known physical mechanisms exist.
>
> 3. A perfectly definite set of _rules_ for combining these processes into whole programs of processing.

They point out that _an_ explanation of an observed behavior of an organism is provided by a program of primitive information processes that generates this behavior. Also, they hold that the appropriate way to describe a piece of problem solving (at this level of detail) is in terms of a _program_ - a specification of what the organism will do under varying environmental circumstances in terms of certain elementary information processes it is capable of performing. They formulated such programs for application to electronic computers producing what they called the 'logic theory machine' (L.T.) and the 'general problem solver' (G.P.S.). They found that these 'simulators' showed many resemblances to the human problem solving process as it had been described in the psychological literature. Thus, they held that this was good evidence that the human problem solving process followed similar programs of primitive information processes.

They summarize their model of an individual's problem solving equipment as "an information-processing system with a large storage capacity (memory) that holds, among other things, complex strategies (programs) that may be evoked by stimuli." The content of these strategies is largely determined by the previous experience of the system and the actual strategy evoked depends upon the stimulus. They point out that the storage of these programs is the reason why the system can respond in complex and highly selective ways to relatively simple stimuli.

We will consider this as our model of a farmer for later discussion. This may seem unwarranted in terms of the evidence which exists but we do so because it is so simple and concrete and seems so acceptable intuitively. Also, it provides us with a thread of continuity which runs right through psychology, human behavior, human problem solving processes and, hence, operations research. It also provides us with a useful conceptualization of a problem and a solution algorithm as we will see later.

A Revision of the Classical Normative Assumptions

In general economists have adopted two different approaches to the study of the managerial processes of farmers. One is the normative approach which considers what the farmer ought to do assuming he conforms to the traditional assumptions of rationality, considerable knowledge, stable ordered preferences, etc. The other approach has been the descriptive approach which studies what farmers actually do. The approach we will follow here will be somewhat between the two. We will follow Nielson in adopting a largely normative approach but like him we will not restrict this to the assumption of a traditional economic man. We will make use of the more realistic behavioral assumptions which are becoming available as a better understanding of the human problem solving process is evolved. These are assumptions recognizing the limited access to information which farmers have that assume only limited computational ability and hence do not assume perfect rationality and maximizing behavior on the part of the individual. As Simon (10, p. 272) points out so effectively:

> "The classical theory is a theory of a man choosing among fixed and known alternatives, to each of which is attached known consequences. But when perception and cognition intervene between the decision maker and his objective environment, this model no longer proves adequate. We need a description of the choice process that recognizes that the alternatives are not given but must be sought and a description that takes into account the arduous task of determining what consequences will follow on each alternative... As every mathematician knows, it is one thing to have a set of differential equations, and another thing to have their solutions. Yet the solutions are logically implied by the equations - they are 'all there' if we only knew how to get to them! By the same token, there are hosts of inferences that might be drawn from the information stored in the brain that are not, in fact, drawn. The consequences implied by information in the memory become known only through active information processing, and, hence, through active selection of particular problem solving paths from the myriad that might have been followed."

The model of an information-processing goal orientated organization along the lines of the model of the human mental equipment postulated by Newell _et al_. provides us with one such set of explanations and assumptions, and the ones which we will make the most use of.

The classical normative assumptions about human behavior might be summarized as those of strict rationality. This assumption requires 1) that a consistent and stable ordering of preferences exists, 2) maximizing behavior, i.e. that the individual will always prefer more rather than less in terms of his preference ordering (16).

Schoeffler (17) examines the theoretical requirements for rational action and infers that they are so strict that nobody could satisfy all of them. He concludes that for practical purposes it would be sufficient if a decision maker's behavior tends towards the desirable norm.

Simon, as we have seen, also recognizes these difficulties in terms of the computational limitations of the individual. He points out that the individual would have to explore so many alternatives and the information he would need to evaluate them would be so vast that even an approximation of rationality is hard to conceive. He suggests (18, p. 79) the distinction between 'objective' rationality and 'subjective' rationality; an action being objectively rational if it truly maximizes his utility and being 'subjectively' rational if it maximizes his utility relative to his actual knowledge of the subject.

In our model we will consider the farmer as attempting to be 'subjectively' rational. This seems a far more reasonable assumption since, however, in the writer's opinion, farmers may seldom manage to be even 'subjectively' rational.

Accepting less than strict rationality as we have suggested above means that we are prepared to accept that the preference ordering may not be so consistent and stable; thus, individuals may not be able to discern small preference differentials and, hence, will be only subjectively rational from this point of view. Shepard (19) indicates much evidence that this is so.

Similarly, accepting less than strict rationality means that we are prepared to accept less than maximizing behavior which implies sub-optimizing behavior. If we accept this, we can see more clearly the logic underlying the theories postulated by psychologists, by Newell, Shaw and Simon, and by economists belonging to the 'satisficing' school of thought, that individuals act by means of setting goals or 'aspiration levels' and exhibit 'satisficing' behavior rather than maximizing behavior.

For our behavioral model we will assume 'subjective' rationality only and the implications which this has in terms of less consistent preference orderings and 'goal setting' or 'satisficing' behavior.

The Revised Model of the Farm Management Process

We will now outline a behavioral model of the farm management process which we will use as a 'norm' for our later discussion of the managerial process.

We conceive of the farmer as the most crucial element in a communications network. He is the coordinator of all the operations going on on the farm. The farmer's managerial activities include:

1. Duties as an individual in which sphere his main managerial function is to have preferences and desires. These may be conscious or subconscious and he must reflect them in a set of overall goals for the farm firm which he formulates, i.e. he functions as a goal-getter for the farm.

2. Duties as a problem-solver when his primary purpose is to gather and process information for the purpose of controlling the operations on the farm to approach as nearly as possible the goals he has set. (This will, of course, include the formulation of subgoals and subproblems.)

3. Duties as a controller in which capacity he must implement the plans arising from his problem solving activity; that is, his duties are to change decisions into observable actions.

4. Duties as a member of society. That is he must accept responsibility for his actions[a]; i.e., the consequences of his actions.

Since we are interested in considering the farm management process in relation to the field of operations research and because of the immense importance of the farmer's activity as a

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[a]We may note that there will be interactions between these duties. In particular, there may be interrelations between the farmer's duties as an individual and as a member of society.

problem solver, we consider the farmer in terms of an information-processing model. That is, we consider the farmer as a goal-oriented organization with a memory of vast storage capacity. The memory contains programs of primitive information processes and other elements in storage which are unique to the particular farmer and result from his past experience. The programs enable the farmer to perform sequences of information processes on the continuous sensory influx and on the elements in the memory. The speed and capacity of the farmer's mental equipment are limited, however, and these limitations result in the farmer's behavior being somewhat less than completely rational.

We can consider this sub-rationality as coming from two causes: 1) Inability of the farmer to express his physiological requirements, values and desires in terms of a set of goals and 2) from inability to compute a plan for controlling the farm which is optimal in terms of the goals outlined. These inabilities reflect inabilities in problem solving activity which is the subject for closer study in the next chapter.

PROBLEM SOLVING IN THE MANAGERIAL PROCESS

In the last chapter we considered some aspects of the overall managerial process and we derived a model using concepts from a wide variety of sources. The purpose of deriving this model was to facilitate further discussion of the relevance of the new O.R. techniques to the farm management process. And, because the modern O.R. methods are of most importance in aiding the process of problem solving (equivalent to information collection and processing), we formulated it as an information processing model of the farm firm.

We also gave consideration to the position of problem-solving in the management process and having already noted the particular relevance of O.R. methods to the problem solving process, we will now make use of our model in giving further consideration to the problem solving process.

The Motivation of the Problem Solving Process

In our model of the management process we considered the farmer to have a set of goals. We have seen how these goals do not exist as an independent set but rather as an hierarchical structure of goals, and we have noticed how many of these goals may be subconscious. It was for this reason that we referred to them as 'physiological requirements, values and desires' forming the normal vague economic terminology applied to them. The origin of many of these goals is obviously obscure and undoubtedly highly individual. Thus, economists have avoided any close scrutiny of these so-called 'preferences' except in a highly abstract and generalized way as 'utility.' Good examples of these approaches are the books by Arrow (20) and Von Neumann and Morgenstern (21). Much attention has been focused on the so-called preference ordering as we saw briefly in section (iv) of Chapter 3. The model which we are postulating, however, follows the approach of cybernetics and considers a system of goals, and these goals, if not achieved, are considered to have weights. It may or may not be a more convenient formulation for the purposes of explicit computations. However, it does enable us to formulate a simple and intuitively very appealing concept of the motivation behind the problem solving process. Thus, we see that problem solving activity will be stimulated when the farmer observes that his present performance and the expectations of his projected future plans fall short of his goals. Or, in the terminology of cybernetics, when 'feedback' i.e. information, indicates a large error between a farmer's operation and that of his goal, problem solving activity will be stimulated.

It is interesting to note the similarity of this concept to the theory of 'cognitive dissonance' developed by Festinger (22). 'Cognitive dissonance' is interpreted as a form of psychological discomfort which is postulated as an important motivating factor. Thus, a farmer is said to feel this internal conflict when:

1. He perceives that any facts, beliefs or opinions

that he holds are not consistent with other facts, beliefs or opinions that he holds.

2. He observes that any of his values conflict with others of his values.

3. He observes that his own behavior is not consistent with any of his values.

4. He observes a disparity between his goals and the achievement of his goals.

It is the author's opinion that our model is a much better conceptualization of the real world behavior of farmers than the more normal construct of a rational, economic man with a more or less continuous system of preferences and who attempts to maximize his 'utility.' One reason is that our model gives us a better explanation of how people in various parts of the world under varying degrees of deprivation can all be more or less satisfied with their results - since they have different goals. We have seen above, how problem solving activity is motivated, but it is also important for us to note here that a problem may exist (i.e. there may be a disparity between a farmer's achievements and his goals) but if feedback, in the form of observations and/or recordings is poor, it may not be perceived by the farmer. Also, as we saw earlier, when the process of cognition is included in our model, a problem may be perceived by the farmer as part of his 'sensory influx' but it may not be recognized as a problem. For example, some new technology might be potentially valuable to a farmer but, if he is either totally unaware of the new technology or is aware of it but does not see its potential for application, it will not be incorporated into his farming activities.

Evidence for the above conclusions is given by the results reported by Lee and Chastain (23) who point out that the perception and definition of problems is a problem in itself, and one to which management should apply itself efficiently. They cite evidence of the inability of farmers to recognize problems from a survey of over 250 Farm and Home Development families in Alabama. They state that over half of the farmers surveyed indicated that they thought their businesses were being run as efficiently as possible, yet the farm business summaries usually revealed basic weaknesses in operation and/or organization.

We can see, therefore, that the identification of problems is indeed an important process and worthy of further discussion.

Problem Identification and Definition

One of the observations included in the last section was that we can define a problem as existing when there is a disparity between an individual's achievements and his goals. And for more complex organizations such as human beings which can predict, we can obviously extend this to include a disparity between goals projected into the future and the corresponding projections of achievements.

We can, therefore, define a problem for many purposes as a triple $(A_t, B_t, \Rightarrow_t)$ where A_t corresponds to the overall state of the world which exists, B_t corresponds to the overall state of the world defined by the farmer's goals, and $\Rightarrow_t$ corresponds to the overall set of possible controlling actions which could be taken to ensure that the goals are achieved as closely as possible. From this we can define a solution to a problem as a set of controlling actions $\Rightarrow^*$ which, if taken, would result in the best possible achievement of the farmer's goals (24).

For the purposes of describing a problem situation as a triple, we can regard the set A_t as a complete and comprehensive 'list' of all the elements or attributes which are used to define the state of the world which exists. Similarly, B_t can be regarded as a 'list' of goals corresponding to the elements or attributes which are used to define the 'aspirational' state of the world. Also, we can regard the set $\Rightarrow_t$ as a 'list' of possible controlling actions. These 'lists' however, can be considered as having a complex hierarchical structure, or, in other words, they consist of related subsets. For example, chestnut trees which are ten years old and twenty feet high are none the less chestnut trees. And, weaner hog production is none the less hog production and hog production is, in turn, none the less animal production.

We have already noted the limited cognitive ability of humans, so let us now consider the fairly widely accepted fact that people can never completely comprehend a real world problem situation; thus, they have to limit themselves to dealing with models composed of elements abstracted from the real world situation. We can denote a model as the triple $(A_s, B_s, \Rightarrow_s)$ and the solution to the model as $\Rightarrow^*_s$ where the subscript $_s$

refers to elements of the model where $A_s \subset A_t$, $B_s \subset B_t$ and $\Rightarrow_s \subset \Rightarrow_t$. However, since we will be dealing mainly with models, it will be more convenient to drop the subscript $_s$, but remember that it is implicit.

In the last section we noted the results of Lee and Chastain who also point out that 'perception and definition of problems is a problem in itself.' They are, of course, pointing out the need to observe any discrepancies between achievements and goals and the need to isolate the important elements of A_t, B_t and $\Rightarrow_t$ which are relevant to obtaining a solution to the problem. That is, we need to abstract a 'model' of the overall problem, the solution of which will give at least a useful approximation to the solution of the overall real world problem. We can, therefore, regard problem-solving activity as consisting of three separate processes:

(i) The process of perceiving a disparity between achievements and goals.

(ii) The process of abstracting the most important elements of the overall problem situation to build a 'model' of the problem situation.

(iii) The process of deriving a solution to the model and translating this into the terms of the overall problem.

It should be noticed that a complete solution to an overall real world problem situation is seldom possible. We can, however, quite often find complete solutions to the models which arise as abstractions from the overall problem situation.

A somewhat different approach is that of Reitman (24)

(25, p. 166) who points out that most considerations of problem solving have dealt with 'well-defined' problems only. He considers a 'well-defined' problem to be one for which there is some given systematic way to decide when a proposed solution is acceptable. Thus, he contends that we have a whole continuum from well-defined problems to ill-defined problems; a problem is well-defined if, when given to a number of different problem solvers, it evokes similar solutions. It is said to be ill-defined if it evokes a whole range of different solutions. We might quote two examples to clarify matters: thus, a problem such as 'to find the solution of a given and determinate set of linear equations' would be a well-defined problem since there exists only one unique solution. On the other hand, a problem such as 'the composition of a piece of music' is an ill-defined problem because even among musicians it would result in many different solutions. Thus, the ill-defined problems are more ambiguous and according to Reitman, this is due to 'open constraints' which can be 'closed' in ways which suit the problem solver.

We can easily identify such a range of problems in agriculture. Thus, a problem such as 'design a set of farm buildings' would be an ill-defined problem, whereas, 'find the combination of hog and corn activities which will maximize dollar returns from ten acres of land and forrowing space for five sows at a time, no other resources limiting and assuming that the production and price data given is known with certainty' would be an example of a relatively well-defined problem.

As Lee and Chastain (23) point out, "A clearly defined problem is one of the prerequisites for sound thinking" and it is also a prerequisite for a management specialist if he is to know in advance that his solution will be acceptable.

Unfortunately, in many cases, it is the definition of the problem which is hardest to achieve. Once this is done, the problem is often virtually solved. Thus, the definition of the problem of writing a piece of music is not complete until the music is written. As Reitman shows in this case, the constraints 'proliferate' as the composing continues until either no solution is possible and the composer has to try another sequence of possibilities or else an acceptable solution is found.

Ill-defined problems are common to the farmer and even more so to the management specialist because it is often not at all easy to define either the farmer's objectives or goals, nor is it easy to define the constraints under which he operates, i.e., the 'amount' of control he can exert.

According to Reitman, therefore, there are two fairly distinct methods for solving problems depending upon whether they are well-defined or ill-defined. The solution of an ill-defined problem is often, to a large extent, a matter of defining the problem; in other words, selecting a sequence of feasible attributes for the prospective solution until either the constraints proliferate to such an extent that no solution exists and another sequence of feasible attributes must be tried, or, an acceptable solution is found.

A well-defined problem, on the other hand, is solved by means of dividing the problem into subproblems with subgoals which will achieve the overall goal. This process proceeds by trial and error until all subproblem(s) can be solved. An example of this hierarchical structure of subgoals, which are said to be in a 'planning relation' to the overall goal, is given by someone solving a geometrical theorem in stages of proving angles equal or unequal, lengths equal or unequal, etc., until finally the theorem is proved. We should note that the solution procedure may break down in either case, for ill-defined problems when there are conflicting goals and for well-defined problems when computational capacity is insufficient.

In reality, of course, as Reitman points out, the problem usually lies somewhere between the two polar types and contains elements of each.

Let us now return to discussion of the problem solving process along our previous lines. It is interesting to note the similarity of the points made by Reitman and Lee and Chastain; thus, according to the latter, problem solving activity depended upon first defining the problem (model), then solving it. In terms of Reitman's approach, this is similar to first solving the ill-defined parts of the problem and then solving the resulting defined problem. However, it is to be hoped that the discussion of Reitman's work has helped us gain some idea of the processes which are involved in first defining and then solving the usual partially ill-defined problem as it is first perceived by the farmer.[a]

The Relevance of the Computer to the Problem Solving Process

We have seen how problem solving usually proceeds by means of constructing a model of some sort as an abstraction from the overall problem situation. We wrote this model as a triple $(A, B, \Rightarrow)$ and noted that a solution was given by a sequence of processes $\Rightarrow^* \subset \Rightarrow$ which when applied to A resulted in B. However, to mentally derive the solution $\Rightarrow^*$ to the model of a problem, we have to go through another sequence of mental processes, $\rightarrow$, which end when the solution, $\Rightarrow^*$, is found. We have already seen how attempts have been made to simulate these mental processes on computers. Also, we have considered some of the differences which occur if the problem is ill-defined or well-defined.

Simon (1, p. 2), as we have already noted, distinguishes between what he calls programmed decisions and non-programmed decisions which correspond roughly to the solution of what we are calling well-defined and ill-defined problems.

According to Shepard (19, p. 260), we can regard the farmer as having a remarkably well-developed perceptual apparatus which

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[a]We will later give consideration to procedures which allow the processes of problem definition and problem solution to be carried on simultaneously.

leads to a 'multidimensional sensory influx' which is then broken down in an extremely complex way to a manageable set of discrete environmental properties and objects. This process of perceptual analysis is then followed by an analogous but reverse process of synthesis and leads to complex coordinated behavior sequences. However, as a result of the technological advance of western society, the synthesis required is becoming more and more complicated (as we saw earlier in Chapter 2). More alternative responses and more detailed responses must be analyzed. Also, it seems that for many of these logical and combinatorial processes 'man is outperformed by the computer with its ability for rapid storage, retrieval, and rearrangement or recombination according to strict deterministic rules.'

Thus, computers are fast taking over the manipulations required for solving well-defined problems but so far they have not taken over the solution of ill-defined problems to any great extent (1, p. 20). In other words, computers are powerful tools for solving problems which require simple manipulation, but they are so far proving to be of little help in the process of model building or abstraction of problems.[a]

The reason why electronic computers are fast taking over the solution of well-defined problems is as follows. If we regard a computer as a machine for manipulating symbols (either mathematical or alphabetical), it is infinitely superior in

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[a]We will make some modifications to this statement later.

speed and accuracy to the abilities of human beings for carrying out similar manipulations.

The main limitations of modern computers would seem to be the restricted memory capacity which they have and the way in which they must be instructed (programmed) to carry out these manipulations. On many of the larger modern computers, however, the memory capacity is reasonably adequate for most purposes. What restricts their use most is the detail with which they have to be programmed and the effort which goes into providing data in a form in which it may be fed to the computer, i.e., its 'perceptual apparatus' is quite poor.

Let us state this in terms of our model of the managerial process to see more clearly the relation of the computer (and, hence, O.R. technology) to our model of the managerial process.

First, the problem is perceived by the farmer as a discrepancy between his achievements and his goals. He then tries to solve the problem by making mental manipulations upon elements in his memory and other data which he may collect. Often these problems are poorly-defined so the processes of definition and solution are carried on together.

Some problems, however, require very many manipulations which are beyond the capacities of the human mind both in terms of speed and accuracy. However, if these problems can be defined and fed to the computer in computer format, then the computer can be instructed to carry out the manipulations and, hence, relieve the farmer of this task. This procedure is apparently worthwhile for quite a number of problems. However, to be able to program the computer to carry out these manipulations we must first be able to specify them in great detail (i.e., normally as arithmetic and logical operations). Thus, if a farmer uses a sequence of mental processes, $\rightarrow$, for deriving a solution, $\Rightarrow^*$, to a particular problem, then to be able to instruct a computer to carry out the same processes, we must be able to specify them in detail. This detailed specification of the process, $\longrightarrow$, is usually not worthwhile for specific problems, the procedure more normally being to specify in this way only programs which may be used in a wide variety of problem situations. These specifications of sequences of manipulations form the so-called computational algorithms of modern O.R. technology. One of the major obstacles to modern operations research is the lack of knowledge of human problem solving processes. Once these are more explicitly known and can be stated as computer programs, it is likely that computers will be able to perform most of the mental processes now peculiar to human 'thinking' (26) and probably many more also.

In the next chapter, we will consider the elements of a problem situation more closely which will be useful later for further consideration of modern operations research technology in the processes of problem recognition, definition and solution.

THE GENERAL FORM OF A PROBLEM SITUATION

The objective of this chapter will be to discuss the elements of problem situations and discuss a particular generalized model of a problem situation. The reasons for doing this are, firstly, that any generalizations which we can make about the structure of problems will facilitate further discussion of the operations research methods now available; secondly, it will help us ellucidate what information is required to define a problem; thirdly, it will enable us to consider the effects on the problem solving process of incomplete information regarding the various elements of the problem situation.

We have already seen how the operations research algorithms can be regarded as sequences of manipulations which are applied to the elements of a model of a problem situation to derive a solution. That is, these algorithms deal with the manipulation of symbols representing the model. It is not surprising, therefore, that mathematics and the theorems it provides is the lifeblood of the study. Many of the results of mathematics which have been built up over the centuries were very valuable in developing the general theory of operations research over the past two decades. In this way the general methodology of most operations researchers has been to build abstract mathematical models of certain operational problems which arise. The results and theorems from mathematics are then applied to these models to attempt a solution of them. This involvement with mathematics are then applied to these models to attempt a solution of them. This involvement with mathematics has resulted in much use of mathematical symbols and notation in operations research and we will not hesitate to make use of mathematical notation in developing a discussion of a generalized problem situation.

General Economic Problems

Economics is often defined as 'the study of the allocation of limited means among competing ends.' And, most of the problems which face the farmer can be considered in this means-ends framework. As Koopmans so aptly puts it, "The analytical separation of preference from opportunity" (26). In terms of our model, the ends are the farmer's goals and the means, which are limited, refer to the control which a farmer can exert upon the variables affecting his farm and, therefore, the achievement of his goals.

We should notice clearly, however, that the underlying assumption in defining economic problems is that if the 'means' are not limited to the extent that the ends compete, then no economic problem exists.

The Production Function Model

One concept of a problem situation is that which is implicit in theory about the production function. Thus, we can consider a farmer's utility (U) as being a function of 'output' variables (y_i) and we can write:

$$U = G\ (y_i) \qquad i = 1, 2, \ldots\ldots m$$

And, these 'output' variables will be outputs from the production process and, hence, will be functions of the 'production variables' (x_j). Thus, we can write:

$$y_i = f_i(x_j) \qquad j = 1, 2, \ldots\ldots n$$

However, there is a tremendous range of production variables and they can be dealt with at all levels of detail. We might define a 'production variable' as 'anything which affects the process of production,' and it is immediately obvious that these range from variables over which the farmer can exert close control to variables over which the farmer can exert no control. This is not a simple classification since there are all shades of gray in between these 'polar types.' As examples, we could regard a farmer as having good control over what constituents he put into a particular feed mix. He has rather less control over the exact date on which he can plant his crops (due to the restraints placed upon him by the weather). He will have very little control over such things as the prices he receives for his products and, finally, he has no control over such things as the weather. However, if we wished, we could consider production variables as belonging to two separate groups. A set which he can control we could call 'action variables' and a set which he cannot control we could call 'event variables.' We can, therefore, write the production function model as:

$$\text{Maximize} \quad U = G\,(y_i) \qquad i = 1, 2, \ldots\ldots, m$$

$$\text{where } y_i = f_i(x_j, z_k) \qquad j = 1, 2, \ldots\ldots.n_j$$

$$k = 1, 2, \ldots\ldots.n_k$$

where the x_j are the action variables and the z_k are the event variables. The limitations upon the set of actions are stated as constraints in the form

$$g(x_j, z_k) \left\{ \leq, =, \geq \right\} 0$$

In parenthesis we might here note that if a farmer is to control the production variables to his best advantage, i.e., to optimize the index U, then he will only be able to do this most effectively if he can predict the future values of those variables, z_k, which are beyond his control. The extent to which he can predict the values of the uncontrollable variables depend upon his ability to isolate 'cause and effect' relationships with other variables which he can control or predict and the distance into the future over which his predictions range. It now becomes clearer why we earlier considered the farmer's management duties to include 'predictions' or 'formulation of future expectations' and 'analysis of alternative plans of action.'

The writer feels that it is important here to realize that in formulating a plan of action, it is important for the farmer to appreciate the <u>degree of control</u> which he has over the action variables and the <u>reliability</u> of his <u>predictions</u> concerning the event variables. These two factors will give him an idea of the amount of uncertainty about the future which he faces. It also allows him to distinguish between the two alternatives for reducing uncertainty about the future.

1. Planning to increase his degree of control.
2. Improving the accuracy of his predictions.

A Generalized Problem Situation

We now return to the main theme of our discussion and consider the elements of a generalized problem situation as they have been outlined by Hildreth (27). Our presentation will follow Hildreth's presentation quite closely.

The relevant parts of a problem are said to be: a set of possible events, a set of possible actions, a set of strategies, a set of consequences, a criterion for ordering the consequences and a function assigning a consequence to each pair consisting of an action and an event.

An event z is one of the set of possible events Z (written $z \subset Z$). It is a variable or combination of variables relevant to the decision-makers welfare and behavior but outside his control. These elements reflect the uncontrollable and unpredictable nature of the farmer's environment. Such events for a farmer might be the occurrence of a certain set of prices or weather.

An action x is an action or a combination of actions which is a subset of the set of possible actions X_z (written $x \subset X_z$).

We add the subscript z here to emphasize that X_z depends upon the events which occur. Some examples of actions for a farmer might be: selection of a crop plan for next year, the signing of a contract, the selling of some corn, etc. To indicate the dependence of X_z upon Z we note that the plan for next year will depend on the availability of capital which will be determined by the weather and last year's crop yields.

A consequence is a meaningful result or combination of results of actions and events. It may take an infinite variety of forms. Thus, net revenue realized from a choice of inputs and actual weather and prices, good seedbeds resulting from careful cultivation and even pride of ownership resulting from recently expanded acreage all are examples of consequences. We could denote the relationship of a consequence y and a pair of actions and events as:

$$y = \eta(x,z) \quad \text{and} \quad y \subset Y$$

then, being the function assigning a consequence to each pair consisting of an action and an event.

A strategy, which we will denote as σ, is a function that designates an action corresponding to any selected event. Thus we can write:

$$x = \sigma(z)$$

It denotes a way for a farmer to react to the uncontrollable events in his environment. We should notice, however, that under certainty, the distinction between an action and a strategy vanishes because all events are known in advance.

Finally, we need a criterion for ordering the consequences. This may or may not be readily available. For the present we will assume that one is available which reflects the farmer's preference ordering.[a]

Under certainty this is fairly simple since there is a one-to-one relationship between actions and strategies. However, under uncertainty and in a dynamic situation, both of which characterize the real world, the relationship between 'preferences,' strategies and consequences is more complicated. Indeed at present there seems to be no precise economic theory to deal with such situations. Frequently consequences are ordered by some real valued function. The function is interpreted as something like net revenue, cost, utility or expected utility. Such a function will be called the criterion function and denoted as ϕ. If we denote the value of the function evaluated for a particular consequence y, as U, we can write:

$$U = \phi(y)$$

In most farm management situations we try to choose the criterion function so that it is fairly easily quantified but on the other hand, still reflects the farmer's preferences quite closely.

The overall decision problem, therefore, is to find the strategy, σ, which will optimize the value of the criterion function over the given set of possible actions for the given

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[a]In the terms of our model, we regard the farmer's preference ordering as being derived from his system of weighted goals.

set of events.

Some simple examples might be:

(1) Z - a set of prices

X - a set of input-output combinations on the production function

y - net revenue

ϕ - the farmer's utility function.

If we then assume that the farmer's utility function increases monotonically with expected net revenue (i.e., the expected net revenue reflects the farmer's preferences adequately), then net revenue can be used as the criterion function.

(2) Z - a set of possible production functions

X - a set of input combinations

y - the resulting input-output combinations

ϕ - the farmer's utility function.

In this case, it might be harder to find a criterion function which adequately reflected the farmer's goals since we would have to determine probably indirectly, how the input-output combinations affected the farmer's utility level. As in the previous example, one simplifying assumption might be to aggregate the input-output combinations resulting from a particular strategy together into a single value such as the expected input-output combination.

The above model described by Hildreth, while allowing for uncertainty in defining the set of events beyond the farmer's control, does not explicitly allow for the dynamic nature of many decision problems. Thus, many decisions made at the present time ramify far into the future and in most cases the further we try to project ourselves into the future, the less adequately we can predict the situation which will exist.

We should perhaps note that uncertainty may surround both future preferences and future consequences (26). Thus, to be quite general, our model needs to be able to take account of uncertainty of future preferences on the one hand and the uncertainty of future opportunities on the other.

Unfortunately, little work seems to have been done to try to incorporate the uncertainty of future preference and hence, the consumer's desire for flexibility of future preferences into general economic theory. The general effect of a consumer's uncertainty over what his future preferences will be would seem to be that he will want to leave certain decisions about consumption until a later date. If, on the other hand, he knew with certainty what his future preferences would be, then it seems reasonable to assume that he would be willing to commit himself to a certain future consumption program at any time. This is not the case in the real world, however, and consumers frequently wish to delay their choices until they feel as confident as possible of their preference expectations.

This has important implications for farm management because it casts doubt on the assumption that a system of preferences exist from which our criterion function can be derived.[a]

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[a] Hence, also, the existence of a set of goals.

As an example, we might consider the case of a farmer who wants to formulate an overall farm plan but has never kept hogs. He does not know until he has had experience of hog-keeping whether he will put some high positive or negative non-pecuniary value on such an activity. In other words, if he incorporated hogs in his overall plan he might find out later that he strongly disliked hog-keeping and want to dispose of them or vice versa. The information on future preferences is just not available.

However, some decision has to be made and some assumption about future preferences must be made in evaluating future programs of action. What assumption is made will depend upon the situation. (It may be that an organization specialist could relieve the farmer's uncertainty to some extent in such situations by reviewing his experience of other farmers' reactions in similar situations.) In the terms of our model we avoid this question by <u>assuming</u> that a set of goals exists.

It is easy and instructive to make this analytical separation between 'preference' uncertainties and 'opportunity' uncertainties in theoretical terms but in our model as outlined by Hildreth, this distinction is not made, uncertainty of either type being aggregated into the set of 'events.' This is deemed acceptable mainly because actions taken to combat uncertainty of either type will be similar in terms of the production plan adopted. For further discussion and a review of the ways of reacting to uncertainty, the reader may refer to Heady (2,p.500).

We can see that the model so far elaborated does allow for uncertainty. It now remains to show how the model can be modified to incorporate the dynamic nature of problem situations.

The Dynamic Model

According to Hicks (28, p. 192), the change from a static to a dynamic system in the theory of the firm requires that two ammendments are necessary. Thus, the elements of the system have to be dated and the values of the criterion function corresponding to the different consequences have to be replaced by discounted values.

We will modify our model in a similar manner thus, we will append time subscripts to the elements to date them and we will replace our set of consequences by a set of state variables ($s \in S$). These state variables will be regarded as defining the state of the system at any particular time. The value of the criterion function evaluated for each time period will then reflect the discounted value of each of the 'states of the world.'

$U_t = \phi_t(s_t)$ where ϕ_t reflects the discounted value. The state variables will be determined by the actions and events occurring in that period and the values of the state variables resulting from the previous time period.

$$s_t = \eta_t(x_t, z_t, s_{t-1})$$

And, as we have noted before, the set of possible actions in a particular time period will be determined by the state of the system (e.g., availabilities of land, labor, capital, etc.).

$x_t \in X_t$

and $X_t = G(s_{t-1})$ where G is a relation defining the bounds upon the set of actions.

We should notice also that as each cycle passes more information will become available. In this way the elements of any or all of the sets defining the problem situation may change. In particular, we might note that although the events Z_t are outside the farmer's control, he may predict which event z_t will occur in each time period: $t=t, t+1, \ldots, t+n$. But with the passing of every time period and accumulation of more information, better predictions of the z_t will be possible.

It is convenient to bring in the concept of a planning horizon at this point. And we can define it here, descriptively, as the length of time over which expectations are formulated - in the above case, n periods.

A Problem Situation as a Quadruple

The previous model which we described as outlined by Hildreth seems to make the implicit assumption common to economic theory that the farmer's goals cannot be achieved, i.e., that the goals are unrealistic. When we consider the farmer as a reflective goal changing unit as we saw earlier and as seem to be the interpretations implied by the work on simulation of human problem solving, we see that this is not necessarily the case. A better interpretation of the situation would seem to be that the farmer has a set of goals and a system which he is controlling. As long as he does not recognize a disparity between goals or achievements, no problem is recognized. However, such a disparity may occur due to either a revision of the farmer's goals or results occurring which are not as good as were expected. In either case, the disparity is not likely to be so large that no reconciliation is possible. (Results of Lee and Chastain, (23), for example). If, therefore, we consider a problem situation in this light, our original model of a triple $(A, B, \Rightarrow)$ seems more appropriate. However, we should perhaps bring another component into this definition to reflect the uncontrollability, unpredictability, and difficulties of measurement, which surround real world problem situations. We will, thus, bring into our model a set of events- $Z_s \subset Z_t$, but, as before, we will drop the subscript s. We should note that Z_t will also have the hierarchical 'list' type structure of the other elements of our definition. Our model can, therefore, be regarded as a quadruple:

$(A, Z, B, \Rightarrow)$ where $A \subset A_t$, $Z \subset Z_t$, $B \subset B_t$, $\Rightarrow \subset \Rightarrow_t$ and

$(A_t, Z_t, B_t, \Rightarrow_t)$ is the actual overall problem situation which exists.[a]

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[a]We conceptualize the overall problem situation as a hypothetical 'model' of infinite detail.

In this model the solution will be the sequence of processes or actions which achieve the goals B in light of the expected (predicted) event z.

Conceptualizations of Farmers and Economists

It is interesting now to note the similarity which exists between our dynamic interpretation of Hildreth's model and the definition above since in a more or less equivalent way, we could write Hildreth's model as:

(S_{t-1}, Z_t, S_t, X_t) where S_t defines the goals to be achieved in period t.

The criterion function ϕ is only needed because we assume 'insatiable preferences' instead of a set of satiable goals which could be expressed in terms of future 'states' or consequences.

It is the writer's opinion that economists should realize that our model of problems and problem solving, which we have derived from psychologists' simulations of the problem solving process, is a more useful one for solving <u>sub</u>problems arising in the practical managerial process.

It is only when we consider the long run effect which occurs as farmers revise their goals to the level of achievement possible that the usual economists' model is appropriate. That means we can distinguish here between problems as they are perceived by the farmer and problems as they are perceived by the economist. The economists' conception is one _optimization_ of the overall problem whereas the farmer's conception is one of _reconciling_ achievements and goals for the models of the overall situation which he recognizes. However, the overall effect of the farmer's management procedure, including revision of goals, is one of attempted optimization.

IMPERFECT INFORMATION AND THE MANAGEMENT PROCESS

The Effects of Imperfect Knowledge

The heading for this chapter implies that in some problem situations complete information is available regarding the elements of the problem. When this occurs, however, it is because either we are only dealing with a very small subset of the elements of the overall real world situation or we are dealing with some hypothetical problem (such as a mathematical problem). It seems true to say that we can never conceive a perfect comprehension of an overall real world problem situation, only of certain elements forming a model abstracted from it. And, frequently it happens that we wish to solve models about which we have only imperfect knowledge regarding the components, i.e., we may not be aware of <u>all</u> possible actions or <u>all</u> events which may occur. We may not be able to predict exactly which event will occur. We may not know the consequences exactly or which consequences result from which actions and events. We may not even know the criterion function exactly, but for our purposes we are assuming that we do.[a]

The question then arises of what difference does this make to our ability to derive the <u>true</u> solution to the problem? It follows as an elementary principle of control theory

[a] As a set of weighted goals.

which we were considering earlier that any solution we derive without perfect information will be unlikely to be the true solution but it is likely to be an approximation of the true solution.

There are many different approaches to the solution of imperfectly abstracted and imperfectly quantified models of problems. One of the commonest methods both in theory and practice used by farmers and economists alike is the assumption of certainty. While this assumption seems to be a legitimate one for static problems in dynamic problems its use involves the danger of investing fixed resources in a way which later turns out to be sub-optimal. In solving dynamic problems, therefore, a farmer's information may indicate a certain sequence of actions but before he invests in a particular plan, the farmer should attempt to measure the degree of uncertainty surrounding his information. If his information appears to be good then the plan will probably turn out to be quite close to the true optimal plan. However, if the uncertainty surrounding the information is high, the farmer may be better off to invest some resources into incorporating some <u>flexibility</u> into his plan (i.e., invest in providing greater possibilities for control in the future). Or, he may prefer to invest in better information with which to formulate his plans. In all cases, he will have to decide between more efficient operation in the present or in the future. Hence, much will depend upon the rate at which he discounts future income.

Other approaches to the problem of deriving solutions under incomplete information have been attempted. It seems that at the present there is no simple and precise answer to the problem. One approach which has received considerable attention has been that of the Game theory. But most of these models hypothesize the situation of complete information regarding all the elements of our generalized problem situation except for the information about which event will occur. For this it assumes complete ignorance. It seems, therefore, that it hypothesizes an extremely rare situation and probably for this reason has not found much practical application.

Any study of decision making under uncertainty seems to involve the calculus of variations which is normally too complicated for most practical purposes, although there seems to be some hope that practical assistance in this direction will come from stochastic programming models (29).[a] So far, however, these models have not received too much attention.

We see, therefore, that as far as helping the farmer to decide how to react to uncertainty in practice is concerned, the majority of O.R. methods are of little help. The only thing which they seem capable of doing is to reduce the

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[a]See also References 30, 31, 32, 33, 34, 35, 36.

uncertainty by allowing better data to be computed and larger, more detailed models to be utilized.

While there seems to be much scope for further study of decision making procedures under uncertainty, it will not be appropriate for us to pursue this subject very far due to (i) the comparatively poorly developed state of this area of theory and (ii) the fact that we are more interested in the procedures actually used by farmers. We will tend to consider only methods of eliminating uncertainty from the model.

The Assumption of Certainty

A factor which is often used for classifying O.R. methods is that of the informational states surrounding the set of events of problems which the methods are designed to deal with. Thus, Eisengruber and Nielson (29) consider the decision making models of farm management as falling within three classes:

i) where the set of events ('states of nature') can be predicted with certainty.
ii) where they can be predicted only by a certain probability
iii) where they cannot be predicted at all.

These refer to the so-called states of certainty, risk and uncertainty respectively.

Farmers' mental processes and, indeed, human mental processes in general seem to encounter great difficulty in dealing with stochastic elements of problem situations. If our model of the human mental processes is at all realistic, this is not surprising since elements of the real world are hypothesized to be stored as discrete data in the memory. These data are constants which do not change except as the result of manipulations of them. The only possibility for dealing with stochastic elements mentally (or on a computer) will, therefore, rely on using discrete data in a deterministic conceptualization of the stochastic processes. Unfortunately, these deterministic conceptualizations are normally much more complicated and are therefore avoided as much as possible. This is no doubt the reason why, in the writer's experience, farmers usually deal with lack of knowledge by first assuming that it does not exist; i.e., they assume that their estimates of the elements of the model are completely accurate. They then modify the solution to the model to make allowances for the dangers of committing resources to plans which later turn out to be sub-optimal. We can examine some of the simplifications which result from the assumption of certainty in terms of our generalized model.

Thus, we noted earlier

$y = \eta(x,z)$ but z is assumed known with certainty

so we can write

$$y = N(x)$$

or, in words, the outcome will depend only upon the farmer's actions. But since his criterion function is

$U = \phi(y)$, we can write $U = \phi(N(x))$

and, hence $U = \theta(x)$.

And he can thus determine the optimal action x^0 by maximizing the value of the composite function θ directly, over the set of possible actions X. Also, certainty means he will not need to specify all the events which may occur - only the predicted event.

Because our main interest is in the O.R. methods in relation to the normal farm management processes as carried out by farmers, we will largely restrict our attention to the O.R. methods which make the assumption of certainty.[a] Unless stated to the contrary, this assumption will be implicit in most of our ensuing discussion.

Similarly, we will deal mainly with static models to simplify our discussion. However, the use of a static model causes little loss of generality once the assumption of certainty has been made. This is because the feature of a dynamic decision model which distinguishes it most from the static model is that of accumulating uncertainty with each <u>sequential</u> decision. However, once the assumption of certainty is made, this distinction disappears.

Similarly, since we will be dealing with certainty, we will not have to distinguish between actions and strategies and will simply refer to the set of actions.

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[a]Although, of course, numerous possibilities for simple modifications of these methods to partially account for lack of knowledge do exist.

THE HIERARCHY OF INTERPRETATIONS OF THE OVERALL PROBLEM SITUATION

We saw in sections (v) and (iv) of Chapter 5 how we could define a problem as a quadruple. For further discussion we will utilize the following nomenclature.[a]

s - a vector of variables defining the state of the system which exists

y - a vector of variables defining the aspirational state of the world or, in other words, the farmer's goals

z - a vector of event variables defining the event which occurs

x - a vector of action variables defining the action taken by the farmer to control the system

(s,y,z,x) - the quadruple defining the model of the problem situation.

And, as before, we can imagine the overall problem facing the farmer as a hypothetical construct in the form of the quadruple (S, Y, Z, X) where the variables defining the vectors s, y, z, and x are subsets of the corresponding sets of variables defining the sets S, Y, Z and X.

The Hierarchy of Interpretations of the Component Sets of Models

We have so far seen that we can define a model as a quadruple of component sets of variables and that the solution to the model is an action x, which, for the given event

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[a]It may be noted that we are defining a problem situation in terms of a model of it.

z, will transform the given state of the system, s, into the desired or 'aspirational' state of the system, y. Also, we have seen how the real world 'operator' or transformation is simulated in the model by the functional operator η, where

$$y = \eta(x,z,s)$$

This functional operator is built up from more elementary operators, or, as we called them in Chapter 3, information processes. Thus, may be a function derived by processes of addition, subtraction, multiplication, division, squaring, etc. These are the arithetic operators derived from the even more elementary processes of logic (30, p. 163) namely, the or-operation, the and-operation and the negation operation. We can regard these three processes as the most basic logic operations from which the more complicated logic operations can be derived and, hence, the common arithmetic operations.

In solving the model any or all of these operations may be performed upon the variables defining the vectors s, y, z, and x. We can, in this way, see that we do indeed have a 'model' in the truest sense of the word. And, it is quite likely as we saw in Chapter 3 that these processes are very similar to the ones carried out in the human mind during the process of problem solving. Indeed, down to the level of the simpler arithmetic operations, it is obvious that to a large extent they are.

Until the last two decades all these manipulations were limited to human mental processes, perhaps aided to some extent by the physical equipment of paper and pencil, abacus, or other simple calculating machines. However, it is now possible to program a computer to perform all these operations upon the entities in its memory (which correspond to variables).

It is our purpose now to consider the form of these variables and the hierarchical relationships between them. We will do so because, as we saw earlier, this hierarchical structure of related subsets seems to be characteristic of the way humans relate their various mental entities (variables) which correspond to the elements of their environment. Evidence for this comes from its intuitive acceptability and because it was one of the crucial elements of the successful computer simulation models used by Newell et al. in (15).

In our conceptualization of a quadruple we have four sets of variables all of which can be regarded as defining the real world counterparts they relate to. That is, we can imagine each variable as corresponding to an element of the real world. But, there is no single representation of these variables which can be said to exactly correspond to the elements of the real world. As we have seen, they are all abstractions and approximations of some degree (15).

For example, we might select three state variables to describe a farm system. These might be r, the value of resources available; c, the quality of the climate, and y, the income it provides. We might thus describe it as a triple (r,c,y) which for a particular farm system might be (5,000; 50; 1000). The reader will notice that these numbers by themselves tell us nothing. For them to be useful we need to know that r = 5,000 defines the value in dollars of resources available each year on the farm. Similarly, we need to know that 50 defines the rating of the climate on a given scale of climate evaluation, and that 1,000 defines the net income in dollars from the farm each year.

We see then that the state of the system is defined by a set of three variables. However, we can easily see, also, that each of these three variables might be defined by or 'classified into' similar subsets of variables. Thus, r might be defined by the values of land, labor and capital available each year; i.e., r = f (land, labor, capital). Similarly, c might be defined by rainfall, length of frost free period, average light intensity and average summer temperature. And, y might be defined by the costs and returns evaluated in dollars per year.

Obviously this process of subdivision is an infinite one and, in any particular model, will have to be terminated at some point where the required vector of all the most elementary variables is still of a manageable size.

In a similar way, we can regard all the other component sets of our quadruple as having this hierarchy of interpretations. (Indeed, we might consider all the variables defining the problem situation as having this hierarchical relationship, the initial partition being that of our quadruple (s,y,z,x)).

Some examples of this structure are given in Figures 10 and 11. We have distinguished in these figures between the variables defining the initial state and the variables defining the aspirational state or goals, but, of course, for the dynamic model, this distinction cannot exist since, in this case, the goals for one time period define the initial state for the next period, etc.

The Isolation and Identification of Variables

It will be clear from the above discussion and examples that to isolate and identify any variable, we need to have three types of information about it.

(i) Its quantitative value[a]
(ii) A list of the attributes defining its identifying subsets
(iii) The relationship between the identifying attributes (their order in the classification and procedures for aggregation, etc.)

To use our previous example, if we knew $700.00 was the value of labor available on the farm, we would know that the

[a]For our purposes we will assume that the value of a variable will be a numerical quantity. However, it might be a color or a shape, etc.

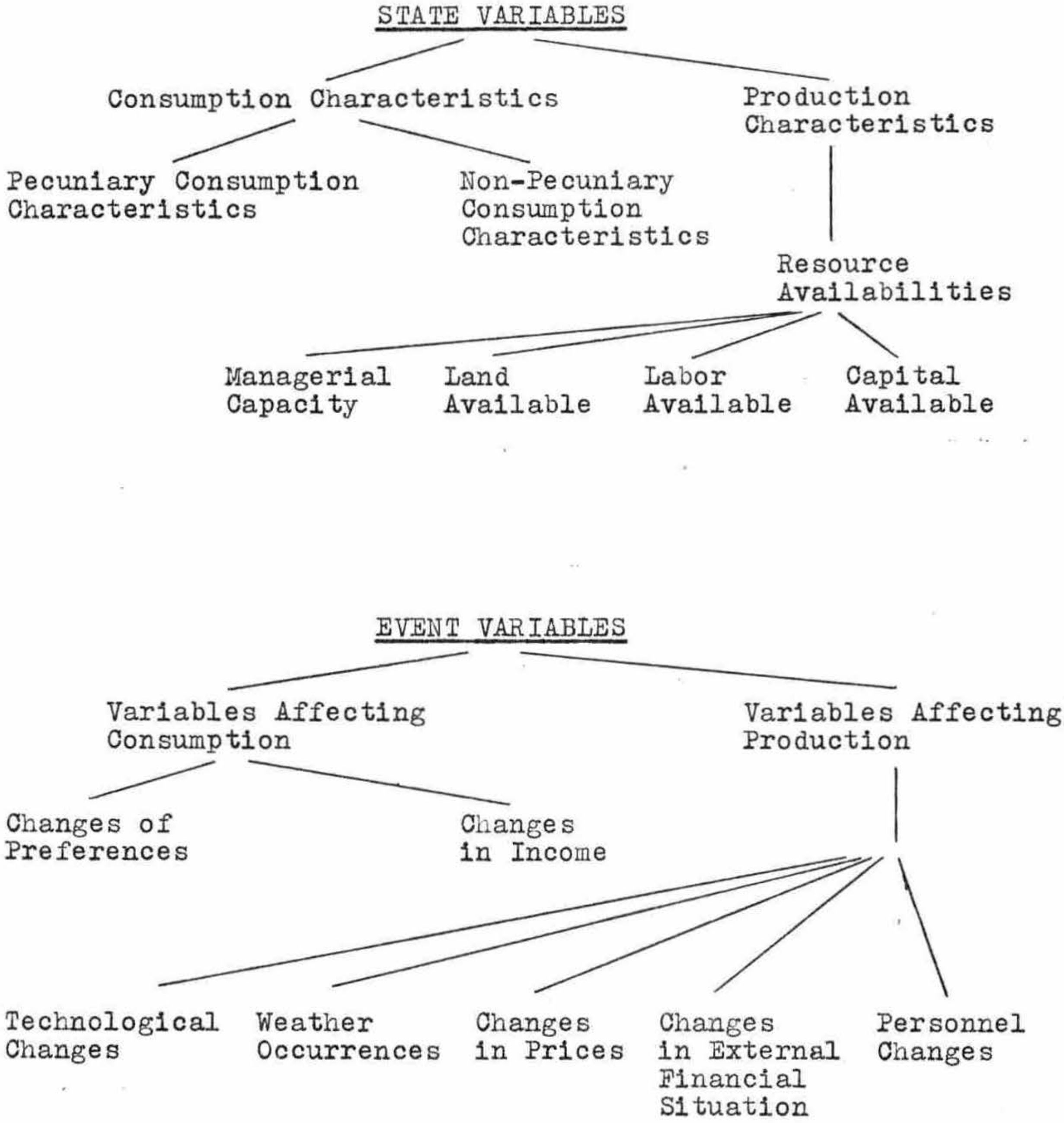

Figure 10. Examples of the hierarchy of interpretations of state variables and event variables

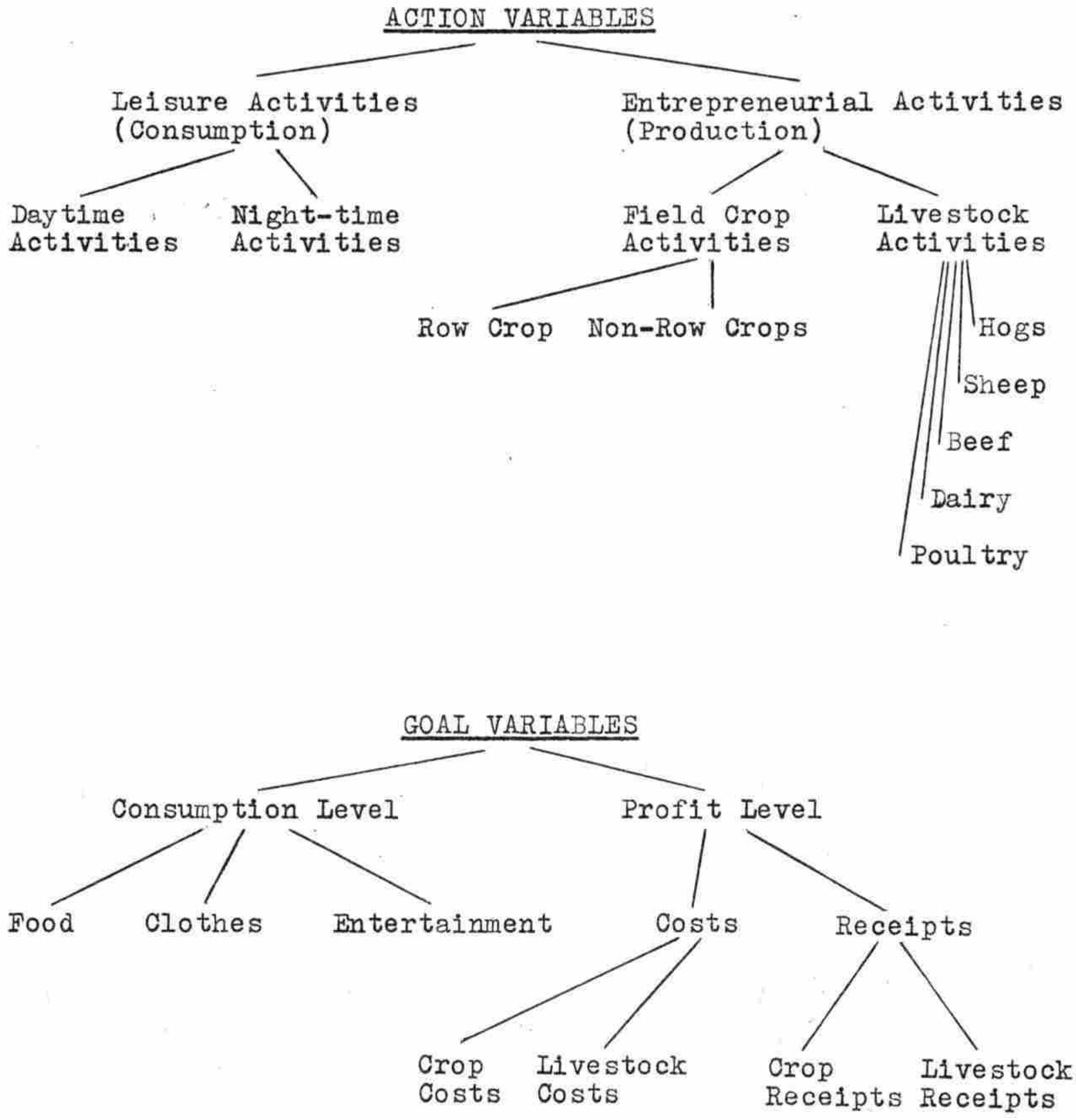

Figure 11. Examples of the hierarchy of interpretations of action variables and 'aspirational' or goal variables

value of the third component variable of r was 700[a]. Conversely, if we found out that 700 was the value of the third component variable of r, then we would know that $700.00 worth of labor was available. That is, we can utilize the identifying attributes which define the related subsets for the processes of both storage and retrieval of data.

The Advantages to be Gained from the Hierarchical Structure

The reader will notice that the existence of the identifying attributes mentioned above makes the processes of both storage and retrieval far more efficient. This is because only one identifying attribute needs to be recorded for each set of data rather than all identifying attributes for each datum individually. Also, the search is restricted to one attribute over each identifying set rather than all attributes over all variables in the model.

The reader will doubtless also notice the applicability of the above remarks to any recording situation; for example, data in a file, figures in a deck of punch cards, or simple mental memorization.

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[a]The reader will notice that even for the purposes of this discussion we have to use the identifying attribute 'r' to identify the set we are referring to!

A further advantage to be gained from the hierarchy of interpretations is that it allows the problem solver to adapt the degree of detail being used to the need for detail in the particular model under consideration and it makes possible the decomposition of the overall model into related submodels defined by subsets of the overall component sets of variables.

As a typical example, a farmer will, mentally, break the operation of his farm down into enterprises (subproblems). Then he considers the operation of each enterprise separately as more detailed submodels and deals with the interactions of these enterprises at a 'higher level' in another submodel. Clearly, this would be impossible without the hierarchy of interpretations we have been considering.

Reasons for the Farmer's Mental Hierarchy of Interpretations

The following discussion is based largely upon the work of Newell and Simon (1, p. 40). Thus, Simon states (1, p. 43) that "hierarchy is the adaptive form for finite intelligence to assume in the face of complexity." He points out that hierarchical subdivision is a characteristic which is common to virtually all complex systems of which we have knowledge. Thus, "Complex biological organisms are made up of subsystems: digestive, circulatory, and so on. These subsystems are composed of organs, organs of tissues and tissues of cells. The cell is, in turn, a hierarchically organized unit, with nucleus, cell wall, cytoplasm, and other subparts." Similarly, he refers to the structures of physics, chemistry and cosmology, electrons and protons, atoms, molecules, particles, planets, galaxies, etc.[a]

He suggests two reasons why complex systems should be hierarchical.

> (1) "Among possible systems of a given size and complexity, hierarchical systems, composed of subsystems, are the most likely to appear through evolutionary processes."

To explain this he gives the following example. Two watchmakers are assembling watches containing 1,000 parts each and are periodically interrupted by the telephone so that they have to put down their work. The watches assembled by the first fall apart completely if this happens before the assembly of the watch is finished; whereas, the watches assembled by the second consist of subassemblies which do not fall apart when they are completely assembled. Obviously, if the telephone interrupts them at all frequently, the second will assemble many more watches than the first.

> (2) "Among systems of a given size and complexity, hierarchical systems require much less information transmission among their parts than do other types of systems."

Thus, as an organization grows, the number of pairs of members of the organization grows with the square (and the

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[a]The reader may note from these examples that the hierarchy of interpretations is facilitated by the clear hierarchy of the structures.

number of subsets even more rapidly). If each member, in order to act effectively, has to know in detail what each other member is doing, the total amount of information that has to be transmitted in the organization will grow at least proportionately with the square of the size. If the organization is subdivided into units, it may be possible to arrange matters so that an individual needs detailed information only about the behavior of individuals in his own unit, and simply aggregative summary information about average behavior in other units. If this is so, and if the organization continues to subdivide into suborganizations by cell division as its size grows, keeping the size of the lowest level subdivisions constant, the total amount of information that has to be transmitted will grow only slightly more than proportionately with size.

If we consider the variables of the farmer's mental model as the equivalent of the members of an organization, we can immediately see the implications of these remarks for the farmer's problem solving processes. Thus, in accordance with the first reason outlined by Simon, the farmer will need to deal with the overall problem by solving the submodel of first one part and then another. (And, in a real world dynamic situation, the problem situation will be continually changing). That is, by the nature of the problem situation the solution process has to be one of discrete steps. Similarly, in accordance with the second reason outlined by Simon, we have already seen that the farmer's mental capacity is one of the factors limiting the problem solving process; thus, any way in which he can cut down on the manipulations required to solve his model will allow a more detailed model to be used. Thus, if the farmer can subdivide his overall model and hence, cut down the number of manipulations (mental transfer of information), then he will be able to deal with more variables in his model. It will be seen that the farmer will have to compromise between ignoring some of the interactions between the variables and excluding some variables.

We might also note in parenthesis how these two factors will compete with the accuracy of the solution of the model since characteristically the stages of computation which immediately precede the final solution do not increase the value of the solution very much.[a] Thus, the farmer may prefer to use only linear relationships with no interactions between the variables except in terms of the restraints upon the set of feasible actions and may prefer to truncate the solution process when it nears the optimal solution in favor of using a more comprehensive model. Indeed, it is probably for exactly these reasons why the technique of linear pro-

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[a]If decreasing returns exist throughout, each stage frequently tends to yield less and less increase over the value of the existing suboptimal solution.

gramming has been accepted so readily in practical situations rather than its more exact and sophisticated nonlinear counterparts.[a]

To summarize therefore, we can say that hierarchy is indeed a common phenomena in the everyday problem solving process used by farmers and some reasons for this are:

(i) Due to the dynamic nature of real world situations the solution process must be intermittent and must, therefore, be solvable in stages.

(ii) By ignoring some of the less important interactions between variables, the hierarchical structure can be used to facilitate a reduction in the number of manipulations required to solve the model and hence allows an otherwise more comprehensive model to be employed.

(iii) It has an important function in increasing the efficiency of storage and retrieval of data (as we saw in the last section).

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[a]We will consider these techniques more fully in the next chapter.

THE ORIGIN OF THE SET OF FIXED GOALS FOR PRODUCTION

As we noted in the last section, the real world situation facing a farmer is dynamic and continually changing; hence, the farmer's mental model of the overall problem as well as its optimal solution will need continual revision. However, obviously, at any stage a model and its solution will exist, even though it may be suboptimal and perhaps infeasible.

In this thesis we have chosen to deal only with the production problem facing the farmer; however, it should not be forgotten that this is only a part of the overall problem situation facing the farmer. That is, as shown in Figures 10 and 11, the farmer also has a consumption problem to solve and the solutions to these two subproblems are highly interdependent. However, at any point in time we can expect that the farmer will have perceived a mental model of both subproblems and their solutions. We can now see that it is these existing solutions to the farmer's mental model which provide the fixed goals for production which we spoke of earlier.

It will again be obvious that since the production and consumption problems are not independent, it will be hard for another person, for example - the management specialist, to solve the production problem independently of the consumption problem. For this to be possible the farmer and advisor must agree on some criterion function $\theta(x)$ which expresses the value in terms of the consumption subproblem of each possible solution to his production subproblem. Alternatively, the farmer might formulate a series of goals for the management specialist; or, what is more common, he may express the appropriate criterion for the management specialist in terms of a functional criterion together with certain other goals to be achieved. For example, the criterion decided upon might be: profit maximization over a planning horizon of four years, as the functional criterion, together with the goals that he does not work longer than ten hours on any one day and longer than eight hours on the average. He might also include the goals that he should keep two horses to ride, or, if the farmer greatly enjoys dairying, he might set the goal of at least thirty dairy cows to be kept.

The reader will notice that the set of fixed goals thus takes the form of further restraints upon the set of actions.

THE MATHEMATICAL PROGRAMMING MODEL

We can regard the mathematical programming model as essentially the mathematical equivalent of the generalized model we have been considering under the assumption of certainty. Certain modifications of this model to take account of risk are possible, however, and the interested reader is referred to the work of Charnes and Cooper (31; 32, p. 113) and Madansky (33) for further information on this aspect in relation to static models. And, in relation to risk in dynamic models one is referred to the multistage decision making approach of Dantzig and others (34). The reader is also referred to the statistical approach of Holt, Modigliani, Muth and Simon (35) and the simulation approach clearly outlined by Zusman and Armiad (36).

The important difficulties involved in accounting for risk in the static and dynamic models seem to be as follows: thus, in the static model, the main difficulty seems to lie in imperfect knowledge surrounding the restraints and hence in determining a compromise between (i) caution required to maintain feasibility of the action decided upon and (ii) the consequent reduction in potential achievements resulting from such caution. In the dynamic model the difficulty lies in the need to find the optimal strategy or 'decision rule' rather than just the optimal action, and this is, of course, made even more difficult by the need, as in the static model, to maintain feasibility at all times.

It will be obvious to the reader that models which include risk are a much better approximation of the real world problem facing the farmer but we will largely omit them from our discussion for the following reasons: (i) We are interested in the O.R. models in relation to the management process as carried out by farmers and we hypothesized earlier that certainty is the assumption normally employed by farmers, (ii) the manipulations required to solve the models taking account of uncertainty are so much more numerous and complicated that the value of most of the relevant O.R. methods available is dubious.

Mathematical Statement of the Model

We noted earlier that the production function model was:

$$\text{maximize} \quad U = G(y_i) \qquad i = 1, 2, \ldots\ldots. m$$

$$\text{where} \quad y_i = f_i(x_j, z_k) \qquad j = 1, 2, \ldots\ldots. n_j$$

$$k = 1, 2, \ldots\ldots. n_k$$

subject to restraints of the form:

$$g(x_j, z_k) \left\{ \leq, =, \geq \right\} o$$

In terms of our generalized problem situation we formulated the problem as that of finding the strategy σ where

$$x_t = \sigma(s_{t-1}) \qquad t = t, t+1, \ldots.. t+n$$

which maximizes the function $V = \sum_{t=t}^{t+n} U_t = \sum_{t=t}^{t+n} \phi\ (s_t)$

where $s_t = \eta_t(x_t, z_t, s_{t-1})$

and $x_t \in X_t$, $z_t \in Z_t$

and where X_t is defined by the set z_t and s_{t-1}

We saw later, however, that with the assumption of a static model under certainty this reduced to:

$$\max_{x \in X} \ U = \theta\ (x)$$

where X is defined by z_t and s_{t-1}

However, it will be clearly seen that in a static model under certainty z_t and s_{t-1} are constants. Thus, we can define the set X of possible actions by restraints of the form:

$$g_i(x) \ \left\{\leq,\ =,\ \geq\right\} \ b_i \qquad i = 1,2,\ldots\ldots m$$

where b_i is a constant derived from the constants z_t and s_{t-1} and x is restricted to be non-negative.

This latter restriction of $x \geq 0$ is a most important one in allowing the translation of real world situations into mathematical form since many real world variables such as acreage of corn grown, numbers of pigs kept, etc., can never assume a negative value. No loss of generality need result from this restriction, however, since any variable x_j which is unrestricted in sign can be replaced by two variables, say x_j and $-x_j$. A negative value for the variable x_j will then correspond to a positive value for $-x_j$.

Finally, therefore, we can see that the mathematical form of the general mathematical programming model can be written as the problem of finding the vector x such that

$$U = \theta(x) \text{ is maximized}$$

subject to:

$$g_i(x) \left\{\leq, =, \geq\right\} b_i \qquad i = 1, 2, \ldots\ldots m$$

$$x = o$$

where x is an n - vector defining the optimal action x.

We should notice that the direction of the inequality of a restraint can be reversed by multiplying each term of the restraint by -1. Also, by the addition of variables to account for 'slack' occurring in any of the restraints, we can change inequality restraints to equalities. Thus, we lose no generality by writing the <u>general</u> form of the restraints as either.

$$g_i(x) \leq b_i \qquad i = 1, 2, \ldots\ldots m$$

or $g_i(x) = b_i$

Also we can transpose terms so that

$$g_i(x) - b_i \geq 0$$

which we will prefer to write as

$$G(x) \geq 0$$

or, as we saw above, with no loss of generality as the equality

$$G(x) = 0$$

Two particular models which have rightly demanded special attention and special algorithms for solving them are the quadratic and linear programming models.

We have already noted some of the arguments for the popularity of linear models. We can now define a linear program as the model which arises when both the objective function θ (x) and the restraints $g_i(x)$ are linear homogeneous functions. In this case, we can write the linear programming in matrix notation as:

$$\text{maximize} \quad U = cx$$
$$\text{subject to } Ax \leq b$$
$$\text{and} \quad x \geq 0$$

where c and x are n-vectors, b is an m-vector and A is an m x n matrix.

Similarly, the quadratic program with quadratic objective (criterion) function and linear restraints may be written

$$\text{maximize} \quad U = cx + x'Dx$$
$$\text{subject to} \quad Ax \leq b$$
$$\text{and} \quad x \geq 0$$

where the quadratic form x'Dx is composed of the n-vector x and an n x n matrix D.

Necessary and Sufficient Conditions for Solving the Model

Among the first people to provide a formal discussion of the necessary and sufficient conditions for 'solvability' of the general programming model were Kuhn and Tucker (37).

In general we may say that it is only possible to solve the mathematical model of the last section, in practical situations, using presently available solution algorithms, if the following conditions are fulfilled (38, p. 200).

- (i) The functions θ and g_i for $i = 1,2,...m$ are continuous concave functions over the set of feasible actions X[a]
- (ii) The variables defining the set of actions X are continuous variables over the whole set
- (iii) At least one feasible solution exists.

Fortunately, most of the problems arising in practice do involve concave functions of θ and g_i. Due to the fact that diminishing marginal returns are normal for most economic problems.

Probably one of the greatest difficulties for the model comes from variables defining the vector x which are not continuous; and, no really satisfactory method for dealing with these so-called 'discrete' variables has yet been devised.

One of the simplest and yet sophisticated algorithms for dealing with the general programming problem has been outlined by Hartley and Hocking (39), although another, apparently satisfactory method has been given by Dantzig (40, p. 471), and numerous others dealing with either the general programming model or certain special situations have

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[a]If it is required to minimize the value of U, then the function θ must be convex rather than concave.

been suggested. In particular, much attention has centered around the solution of the quadratic and linear programming models. Both these models are now solvable in a routine way and computer programs for both are now readily available (41, p. 123), (42). The reader will notice that the necessary and sufficient conditions for solvability are automatically satisfied for the continuous linear model if a feasible solution does exist; also, for the continuous quadratic model if the matrix D is negative definite or semi-definite and at least one feasible solution exists.[a]

The Dual Formulation and Some Interpretations

It has been said that the problems of allocation and value are inseparable. We will now attempt to show this more clearly below.

It has been shown, initially by Kuhn and Tucker (37) and by others more recently (38, p. 201) that if we take the programming problem

$$\max. \quad U = \theta\,(x)$$

$$\text{subject to} \quad G\,(x) \geqq 0$$

$$\text{and} \quad x \geqq 0$$

where the functions $\theta\,(x)$ and $G\,(x) \equiv \{g_i(x) - b_i\}$ are continuous and concave over the set X and formulate the LaGrangian expression.

$$\phi\,(x,y) = \theta\,(x) + y(G(x)\,)$$

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[a]See for example Gass (41, p. 173) and Boot (42).

then if x^o is a vector which maximizes the value of the objective function U, for the given restraints, then there exists an m-vector y^o such that $\phi(x^o,y^o)$ is a saddle point of the function $\phi(x,y)$, that is:

$$\phi(x,y^o) = \phi(x^o,y^o) = \phi(x^o,y)$$

Also, it has been shown that the condition that $\phi(x^o,y^o)$ is a saddle point, is a necessary and sufficient condition for the solution to be the optimal solution of the programming problem.

In other words, for the purposes of finding the optimal solution of the problem, it is immaterial whether we do so by finding the vector x, which maximizes the value of the LaGrangian expression, or the vector, y, which minimizes the expression. These two approaches correspond to what are often called the primal and dual solution procedures. However, to solve the problem it is necessary to find the optimal vectors for both x and y. This is because the attainment of a saddle point is the criterion which tells us we have reached the optimal solution.

It will now be clearer why we mentioned at the beginning of this section that the problems of allocation and value are inseparable problems. Thus, let us regard the vector x as defining an allocation between alternative control variables achieving the maximum value of U, then we can regard the vector y as defining the marginal values associated with the constants b_i which we derived from variables defining the initial state of the system; or, in other words, the element y^i of the vector y will be the imputed marginal value of the i^{th} variable b_i. We can write

$$y_i = \frac{\partial U}{\partial b_i} \Bigg|_{x = x^o}$$

Since b_i can be regarded as a variable defining the state of the system and corresponds to an entity which is in short supply and which limits the level of achievement which can be attained, it is natural to regard b_i as defining the quantity of a particular 'resource' which is available. The variable y_i will then define the marginal value of the i^{th} 'resource.' Naturally, if the resource is not limiting the level of the optimal solution, this imputed marginal value or 'dual price' will be zero.

All the algorithms known to the writer for solving the general programming problem (under the conditions of continuity and convexity outlined above) utilize iterative computational procedures. And, in general, it seems true to say that they iterate by alternately calculating provisional <u>solutions</u> and then the corresponding provisional <u>dual prices</u>. Each provisional vector indicates a way of improving the estimate of the other optimal vector. In this way each iteration gives a closer approximation of the optimal solution.

The solution process is said to <u>converge</u> to the optimal solution. Some algorithms converge in a finite number of iterations and some are infinite processes which have to be truncated when a sufficient approximation is obtained. It is yet another advantage of the quadratic and linear models that they can be solved by algorithms which converge to the optimum in a finite number of iterations.

THE OPERATIONS RESEARCH METHODS IN RELATION TO THE FARMER'S HIERARCHICAL MENTAL MODEL

The Purposes and Uses of the Operations Research Techniques

It should be clear from our previous discussion that we can regard the farmer's conceptualization of the overall problem situation facing him as a complex hierarchy of submodels. Also, because he faces a dynamic problem situation, the farmer will need to be making continual revisions to the form of his overall model and its solution as new information becomes available.

Naturally, therefore, if this is a correct interpretation of the management processes of farmers, the objective for the management specialist will be to use the O.R. methods currently available to assist the farmer in the manipulations required to formulate and solve this hierarchical model.

We have seen how the changes occurring in the problem situation facing the farmer will mean that revisions of the structural and quantitative form of the farmer's mental model, and its solution, are needed. And, we noted how revisions of the comsumption submodel and its solution normally implied a revision of the goals for production. Also, we earlier classified the manipulations of this hierarchical mental model into three different processes: (i) problem recognition, (ii) problem definition, (iii) problem solution. We will now proceed to consider these processes in somewhat more detail and indicate how the various O.R. procedures can assist in each process.

It is often stated, for example by Hutton (43) and Reitman (24), that the modern O.R. methods are only of value in solving the model once it has been defined. It is hoped that the following chapters will help to show how, in fact, they can also be regarded as helping in recognizing problems and in formulating and quantifying models.

The Problem Recognition Process Extended

Earlier in our discussion we defined a problem to exist when a disparity existed between the farmer's goals and the achievement of his goals. Let us now consider this in terms of the hierarchical model which the farmer conceptualizes. We see that the farmer's production goals will correspond to the state which should result from implementing the solution of his production model. Any disparity between goals and achievements will imply an inadequacy in the farmer's mental model and naturally will stimulate the farmer to revise his model and the mental solution derived from it. This seems a relatively acceptable intuitive interpretation of the real world action of farmers, but before we proceed any further, however, we should perhaps recognize at this point that we can now consider two elements of the solution to the model. The usual '<u>solution</u>' or '<u>action</u>' to be implemented, and the <u>imputed dual prices</u>. Thus, we can also recognize an inadequacy in the model when there is a possibility for a farmer to relieve one of the restraints at a marginal cost which is less than the dual price (marginal value). For example, assume the availability of labor is a restraint upon the solution of a model and has a dual price of \$10.00 per hour imputed to it. If the farmer is aware that he can hire labor at \$1.00 per hour, such a disparity of values will also imply an inadequacy in the model or, in other words, the existence of a problem.

It is unfortunate that the computation of dual prices is a much more difficult calculation than the process of monitoring achievements. Thus, in practical situations problems seem to be much less frequently recognized as disparities in values. But, as a consequence of the theory about the saddle point of Chapter 8, part (iii), it follows that theoretically both concepts are necessary in problem recognition.

The Approach of Comparative Analysis

Much interest, particularly in the U. K., has centered around the procedure of comparative analysis. This is a procedure whereby indices of performance are calculated for a particular farm for comparison with the averages from similar farms in the neighborhood (44, p. 27). In the terms of our discussion, we might regard each of these indices as a goal or subgoal and consider each in turn as identifying a problem if the index is 'below average.' Unfortunately, there are many diffdculties associated with correctly interpreting the indices which are calculated. These have been pointed out by Candler and Sargent (45). However, in some cases, such as the use of the method to identify organizational weaknesses on below average farms, the method does seem to have some practical value (46). The writer would suggest that the difficulty of using the method for improving the organization of average, or above average farms is due to the fact that no attempt is made to compute the dual prices. And, we have already seen how necessary these seem to be in any optimizing procedure.

It should be noted, however, that the computation of 'standard figures' or 'indices of performance' is a relatively straightforward process when carried out with the aid of a computer. Hence, much use is made of comparative analysis procedures both in the United Kingdom and the United States of America.

AN INTERPRETATION OF THE MATHEMATICAL PROGRAMMING ALGORITHMS IN THE PROBLEM SOLVING PROCESS: A LINEAR PROGRAMMING EXAMPLE

It will be clear that the recognition of a problem corresponds to the recognition of an inadequacy in the model. And, we have also noted that dual prices are factors assisting in the process of problem recognition. But dual prices are only available when imputed from an existing model. Thus, it would seem that the processes of recognizing a problem and defining and solving a model are inextricably interrelated. We will show this more clearly in a moment.

The writer feels that it is worth noting that we can interpret very many mathematical programming algorithms as a combination of all three problem solving processes. Thus, there seems to be an interesting generality about the process of first recognizing a problem, then defining it, and finally solving it. In more concrete terms these processes can be regarded as corresponding to the processes of (i) recognizing an inadequacy in the model, (ii) revising the model (a process requiring both the identification and quantification of new elements of the model) and (iii) solving the revised model.[a]

It should be noted that to be able to simulate the mental

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[a]Although, as we have already noted, the process of solution may be a trivial one when the processes of recognition and definition have been completed.

manipulations of a farmer in these three processes for the production problem alone, we need to be able to state the criterion as a function θ (x) rather than as a goal-vector, y, of fixed goals. This allows us to 'simulate' the revision of goals which would result from the change which the farmer would make to the solution of his consumption subproblem at each iteration. It will be noticed that it is the provision of this functional criterion which allows a mathematical programming formulation of the model.

We have already noted some of the reasons for the popularity and value of linear programming. Indeed, at present linear programming seems to be almost the only programming algorithm which is used extensively in practice. And, for the reasons we have outlined, this situation seems likely to remain. Because of this predominance of linear programming and because we do not wish to become involved in vague generalizations, we will now outline the way in which we can interpret common linear programming procedures as carrying out the three processes of problem recognition, definition and solution. It will be left to the reader to generalize this interpretation to other models and their solution algorithms.

The Linear Programming Situation and Model

Let us assume that a farmer faces an overall problem situation which can be thought of as a hypothetical quadruple which exactly describes the real world situation in infinite detail. And, let us assume that the relationships are linear; that is, that $\theta(x)$ is a linear homogeneous function and that the restraints $g_i(x)$ are also linear homogeneous functions. Also, let us assume that the function $\theta(x)$ is given.

To solve the production problem in such a situation it will be necessary to construct and solve a linear programming model of the form

$$\text{maximize} \quad U = cx$$

$$\text{subject to} \quad Ax \leq b$$

$$x \geq 0$$

where c is an 1 x n vector of 'net prices'

x is an n x 1 vector of 'activity' levels defining a solution

b is an m x 1 vector of 'resource' availabilities

U is a scalar defining the 'income' from any feasible solution

A is an m x n matrix of 'input-output coefficients'

We have seen that there is an infinite hierarchy of interpretations such that the problem can be dealt with at all levels of detail, but in practice the level of detail which can be employed is very limited.

Now let us assume that the farmer is operating a particular farming system which corresponds to the solution of a particular model defined by (B_o, b_o, c_o); where B_o is an

$m_o \times m_o$ matrix of 'basis' vectors which span the 'decision' space E^m, $b_o \subset b$ is the vector of resource availabilities which 'define' the state of the system in terms of the limiting resources, c_o is a vector of net prices or income coefficients for the activities defining the solution vector x_o.

The m x 1 solution vector, x_o, will be given by

$$x_o = B_o^{-1} b_o$$

Similarly, the dual prices of the limiting resources will be given by the m x 1 vector y_o where

$$y_o = c_o B_o^{-1}$$

And, owing to the saddle point theory, y is the solution to the dual linear programming model:

$$\text{minimize} \quad U = b_o y$$
$$\text{subject to} \quad B_o' y \geqq c$$
$$y = 0$$

The Recognition of a Problem

We can now examine some ways in which a problem may occur and the way it can be recognized in terms of the linear programming model (41, p. 132).

Ways in which a problem may occur

Naturally problems exist all the time as no farmer will maintain a perfect solution to the problem situation he faces. However, it would seem that he will need to be eternally watchful for: (i) changes in his criterion function,

(ii) changes in the resource availabilities, (iii) changes in the input-output relationships (technological changes). It may be that a problem always existed but was never recognized or solved but even if it was, the model and its solution will need revising because of the above changes which frequently occur.

Ways in which a problem may be recognized

It seems that in terms of the linear programming model a problem may be recognized in any of the following ways.

(i) Recognition of a profitable activity to be included in the model.
(ii) Recognition of an unprofitable activity to be removed from the model.
(iii) Recognition of an infeasibility in the model.

A profitable 'external' activity will be recognized by calculating:

$$\frac{\partial u}{\partial x} = \Delta_j = y_o A_j - c_j$$

where A_j is an activity external to the model of basis vectors. For a more profitable activity Δ_j will be positive.

An unprofitable activity will be indicated by a positive value of Δ_j for a 'slack activity' external to the 'model.'

A problem of infeasibility of the 'model' will be recognized if for any restraint vector A_i external to the basis:

$$A_i x \geq b_i$$

where b_i is the availability of the i^{th} 'resource.'

Naturally, an inadequacy will also be recognized if the problem situation corresponding to (B_o, b_o, c_o), changes to (B_o^*, b_o^*, c_o^*). That is, if only quantitative changes are required in the model and its solution.

It is hoped that, for linear programming procedures at least, we have shown how they can easily be interpreted as aiding in problem recognition.

The Definition of a Problem

We will regard the process of problem definition as equivalent to the process of model revision. But, it is important to realize that we can distinguish two aspects of the process of revising a model. Thus, we can consider the process of revising the <u>structure</u> or qualitative form of the model and the <u>numerical</u> or quantitative form of the model. That is, we may wish to include or exclude variables and/or restraints from the model, which we will call a structural or qualitative revision; or, we may merely wish to revise the actual numerical values of certain variables or relationships in the model. We will call this a 'numerical' or 'quantitative' revision of the model.

Obviously, the linear programming algorithm will not assist in any quantitative revisions except of course in revisions to the solution implied by revisions of the other variables. Revisions of a numerical type are normally obtained by estimation from historical data which must be recorded and processed. However, we will consider this briefly, later, together with the potential value of electronic data processing in this field. For the purposes of our present discussion, we will assume the availability of such data and show briefly how linear programming procedures can be regarded as assisting in the process of revising the structural form of the model.

Inclusion of activities allowing greater profitability

As we saw earlier in this chapter, a structural inadequacy in the model can be recognized when an activity is recognized for which Δ_j is positive. When this happens, it is necessary to include the activity in the model. This can occur in either of two ways. Thus, the new activity can replace another activity in the model, or, it can be added to the model together with a new and corresponding limiting restraint. It may be noticed that this process is almost exactly that of the revised simplex algorithm.

Exclusion of unprofitable activities

In terms of linear programming manipulations, this procedure can be done quite simply by replacing the activity with the corresponding slack activity, if such a slack activity is defined. If the corresponding slack activity is not defined, i.e., if the restraint is an equality restraint or a minimum restraint, then it will not be legitimate to exclude the activity from the model. However, if the slack is defined, it can be used to replace the unprofitable activity in the model, and then both the slack activity and the restraint now corresponding to it can be ignored or stricken from the model.

Removal of infeasibilities

When a problem of infeasibility of the structure of the existing model is recognized, it must be removed. If the infeasibility is due to some important restraint which is omitted, it is not difficult to include it in the model, but it will mean that another restraint becomes inactive and will have to be removed. The process of replacing the appropriate restraint with the more limiting restraint will therefore require several computational steps. If the infeasibility is due to activities in the model at a negative level this is most easily rectified by applying the dual simplex procedure (41, p. 149).

It is hoped that the above somewhat brief outline will show how, by regarding the existing basic solution as the 'model,' we can interpret common linear programming procedures as assisting in the structural definition of the model of the system.

The Solution of the Problem

We pointed out earlier that the process of solution of the model was often trivial once the model had been defined. This is clearly demonstrated now since the solution of the

n^{th} revised model is given by calculating

$$x = B_n^{-1} b_n \qquad \text{and} \qquad y = cB_n^{-1}$$

The reader will recognize that this is only a small step after each revision to the model has occurred.

Implications of the Interpretation

It can be noted that contrary to what is often suggested (for example, by Lee and Chastain (23)), the processes of problem recognition, definition, and solution, are all inseparable processes in real life. This is because it seems that they can only be interpreted in terms of the revision of an existing model. We can only regard them as separate processes as we saw above, if we regard them as steps in the revision of a model of an existing problem situation. It is seldom possible to recognize a problem situation, define a model and solve it in three separate stages since a problem is only recognized as an inadequacy of an existing model (either mental or 'physical'). That is, most problems are ill-defined[a] to a certain extent so that the processes of definition and solution must be carried out together in a joint, progressive and iterative procedure.

It is accepted that the above example considers only the linear programming procedures but it will be seen that the above remarks relate to all the nonlinear programming

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[a]Discussed more fully in the next section.

procedures also. This is so because they all adopt a similar iterative procedure which can be regarded as the equivalent of performing cyclically the processes of problem recognition, definition and solution in the revision of an existing model and its solution.

THE CHARACTERISTICS OF AN ILL-DEFINED PROBLEM CONCEPTUALIZED

It is worth noting at this point that we can now conceptualize at least some of the characteristics of an ill-defined problem. We have already noted that both qualitative and quantitative specifications are required to define a model completely. Surely, therefore, an ill-defined problem is one which fails to specify exactly the model which it implies. Thus, because of the hierarchy of interpretations which we mentioned earlier, a whole range of models may satisfy the specifications and, hence, also a whole range of solutions may result.

Common nomenclature seems to infer that a problem may be regarded as 'well-defined' if it exactly specifies only the structural form of the model it implies. We consider a well-defined problem to require quantification of the implied model, also. We do this because if this definition is not adopted we may be able to define a problem but not be able to solve it (because we may not be able to quantify it), an observation which seems somewhat contradictory.

THE NUMERICAL DATA AND QUANTIFICATION OF THE MODEL

We have seen how we can consider the process of defining a model as consisting of the two processes of (i) specifying the variables which define the elements of the model and (ii) the quantification of the variables and relationships between them in numerical terms. We have also seen how the mathematical programming procedures can be regarded as helping in the first process but not in the second - that of quantifying the model. We will now consider the processes involved in providing a supply of the necessary data for this purpose.

The Mental Processes of Quantification Used by Farmers: Their Strengths and Weaknesses in Relation to the Electronic Computer

Earlier, in section (iii) of Chapter 4, we noted that we could regard the farmer as having a remarkably well-developed perceptual apparatus. This provided him with a 'multidimensional sensory influx' which was broken down in an extremely complex way to a manageable set of discrete environmental properties and objects. These were then stored in memory for later use in the problem solving process (19, p. 260).

We have also seen how we can regard the farmer's memory as a vast store of recorded data which we can now regard as defining the farmer's 'past experience.' It is unfortunate however, that this store of data leaves much to be desired in terms of quantifying structurally defined models.

Let us regard the model to be quantified as a mathematical programming type of model. It can now be seen that the data which is required is that necessary to quantify: the criterion or objective function, $\theta(x)$, the restraints, $g_i(x)$, and the 'resource' availabilities, b_i. This does not at first sight seem too difficult. However, it should be remembered that the form of the data remembered by the farmer initially will be observations about the three sets of variables which we can regard as defining the farmer's past experiences, namely:

(i) The actions which the farmer took
(ii) The events which occurred
(iii) The states of the system which existed at a particular time

The function $\theta(x)$ then has to be derived by computing the function $\phi(\eta(x \mid z \text{ and } s))$ where z is the predicted event and s is the existing state of the system. And, the restraints have to be calculated as functions giving the 'resource' requirements of each activity as a function of the variables defining the solution vector, x.[a] We see, therefore, that the estimational problems are in fact very complex.

The difficulties are aggravated by the fact that even

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[a]The reader is referred to Heady and Dillon (47) and Johnston (48) for further details of estimation procedures.

if the farmer's past experience were memorized perfectly (and it certainly is not) some data would still be required from outside the farmer's 'experience.'

Finally, we might mention the errors which always tend to creep into human mental calculations and the way in which they can quickly invalidate any more sophisticated estimations the farmer may make.

To summarize, we can say that the farmer's perceptual apparatus gives him a considerable advantage over the computer but the speed and accuracy with which he can manipulate and utilize this stored data seems far inferior. Also, for many situations, the farmer's 'past experience' may lack all the data required.

In parenthesis, we should note that here is yet another reason why linear programming has become, and is likely to remain, a more popular procedure than its more sophisticated non-linear counterparts since it requires a minimum of data. Also, the above estimational difficulties are probably an important reason why farmers seldom seem to compute anything more complicated than a linear functional relationship.

The Potential for Computerized Data Processing

It will be obvious from the remarks of the last section that much scope would seem to exist for utilizing the farmer's perceptual apparatus to record data about the system, and then utilize the superior ability of the computer to manipulate the data for quantifying the elements of problem situations which arise. Indeed, much work is at present being done in the United States and other countries to do just this. The interested reader is referred to Beer (49), Eisgruber (50), Plaunt (51) and the 3rd I.B.M. Symposium (52) for further information on the so-called data processing systems which are being developed.

It is worth noting, as we saw earlier, that any system designed for the recording and manipulation of stored data will have to make use of the hierarchical structure of identifying attributes for the process of storage and retrieval of the data, and the selection of the appropriate identifying attributes for these purposes will be one of the most crucial factors deciding the success of the system. It may be noted that the selection will depend upon a compromise between (i) the efficiency of manipulation, (ii) simplicity of coding the data for input to the computer, and (iii) similarity with the most common classification used by farmers.

THE HIERARCHY OF INTERPRETATIONS AND MODEL DECOMPOSITION

We have already noted the hierarchy of interpretations of the real world which the farmer uses and we have noted that two of the advantages to be gained from this hierarchy of interpretations are (i) greater efficiency of storage and retrieval of data and (ii) the ability to decompose the overall model into related submodels which may be solved separately. We now wish to describe further the way it will allow the decomposition of the overall model.

The Decomposition of the Overall Model

It will be intuitively obvious to all who are familiar with the mental processes of farmers that they consider the problem situation facing them as separate submodels as much as possible. This is also reflected in the multitude of such 'subproblem' situations that have attracted the attention of operations research workers and agricultural economists. Thus, production functions have been calculated for all classes of livestock, and inventory problems concerning such things as optimal machinery stocks and feed reserves. Fairly comprehensive lists of references to these applications have been given by Kopetz (53) and Hutton (43).

The question might be asked of what the relationship is between these submodels which allows them to be treated separately. The answer would be that they are to a large extent independent subproblems; that is, the solution to one model is largely unaffected by the solution of any of the others. Or, in other words, there is little interaction between these submodels and other submodels. It seems hard to conceive of a situation where absolutely no interaction occurs, but in some situations this does seem to be a reasonable acceptable simplifying assumption.

The question then arises of how we can conceptualize the origins of these interactions. This is an extremely complex question but if we consider the mathematical programming model it seems that we can distinguish two forms of interaction, namely, interactions due to the objective or criterion function and interactions due to the restraints. Both forms of interaction can, theoretically at least, be dealt with in the generalized programming model, but only the simpler interactions such as we find in models with linear restraints and a quadratic objective function are dealt with in most practical situations. More common in practice, both technically among O.R. workers, and mentally among farmers, is the linear programming model[a] which assumes no interactions via the objective function and only linear interactions in the restraints.

It is unfortunate that more work has not been done upon

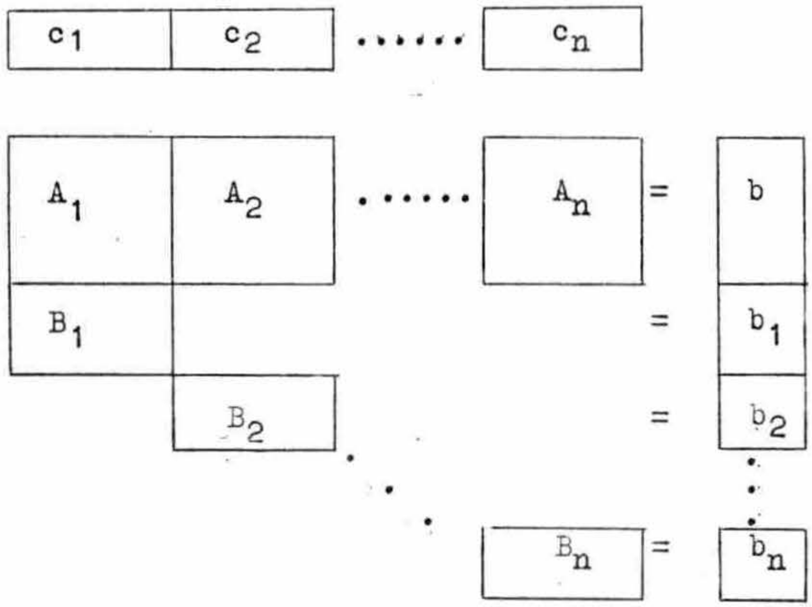
[a]We are, of course, referring to the general heuristic linear procedures of farmers.

elucidating the principles of decomposing programming models into related submodels as there seems little doubt that much potential for the use of such principles does exist. The reason for this is that at present the advisory or extension worker is faced by a bewildering array of submodels of isolated problem situations but at present there seems to be little theory to show him the relationship between these models or how, for example, they might be grouped together to form an overall advisory model which would relate them one with another.

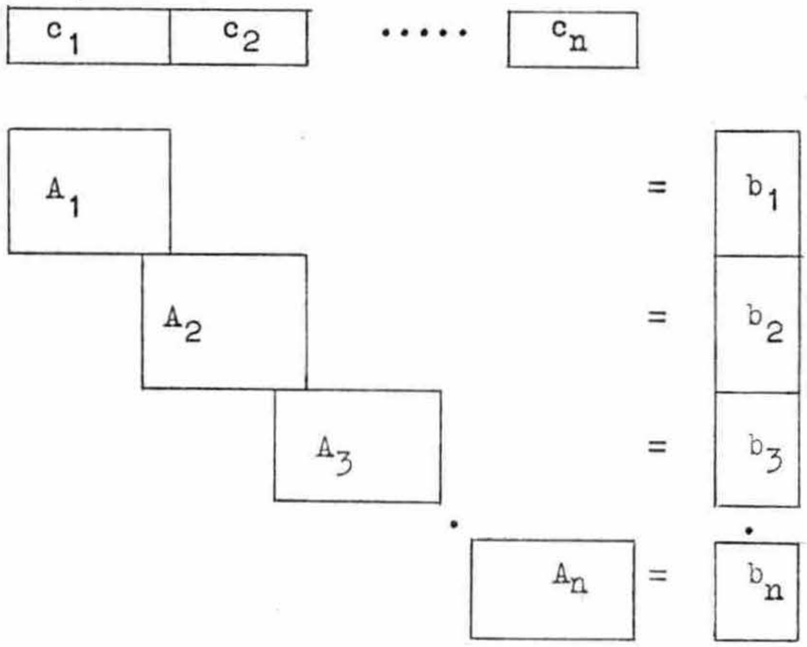
Some work upon decomposition principles in linear programming has been done by Dantzig and Wolfe (54), Beale (55), and others. We will only consider the decomposition principles elucidated by Dantzig and Wolfe, here, however, because their work clearly shows the utilization of the hierarchy of interpretations in the decomposition and seems to have the greater practical value.

The General Form of the Dantzig-Wolfe Decomposition Principle

In Figure 12 we see some configurations of the input-output coefficient matrix which can occur in linear programming models. Such configurations can be utilized to decompose the overall model into submodels and Dantzig and Wolfe have provided an algorithm which allows these submodels to be used in an iterative procedure to attain an optimal solution



A Block Angular System



A Multi-Stage System

Figure 12. Some examples of the coefficient matrix configurations found in linear programming models which allow decomposition of the overall model

to the overall problem. It is a procedure which has many similarities to the iterative processes we might expect a farmer to use as he continually revises submodels of his overall hierarchical mental model. Briefly, the general procedure may be outlined as follows (40, p. 455; 41, p. 166).

Let us take the block-angular configuration of Figure 12 which, it will be noticed, can be regarded as a system of subproblems which are independent except for the set of restraint rows, $\sum A_j X_j = b$, which interact and effectively 'tie' the subproblems together.

The problem may be written as that of finding the vectors, x_j, for $j = 1,2,\ldots..n$, such that

$$\sum A_j X_j = b$$

$$B_j X_j = b_j$$

with $\sum c_j X_j$ a minimum

where A_j is $m \times n_j$, B_j is $m_j \times n_j$, c_j is $1 \times n_j$, b is $m \times 1$, b_j is $m_j \times 1$ and X_j is $1 \times n_j$.

However, for solving this problem we consider a '<u>master</u> program' normally referred to as the extremal program, and several sub-programs.

Let us define

$$P_{jk} = A_j X_{jk}$$

for the extreme point k of the set of extreme-point solutions X_{jk} of the convex set of solutions S_j for the j^{th} subprogram

$$B_j X_j = b_j$$
$$X_j = 0$$

Also, let us define

$$c_{jk} = c_j X_{jk}$$

The 'extremal' program then is to find the values $s_{jk} \geqq 0$ which satisfy for all j and all k

$$\sum_j \sum_k P_{jk} s_{jk} = b \qquad (12.1)$$

$$\sum_k s_{jk} = 1 \qquad (12.2)$$

with $\sum_j \sum_k c_{jk} s_{jk}$ a minimum.

This is so because we assume that the set S_j is bounded for all j. Also, because it is a convex polyhedral set, any point within S_j can be written as a convex combination of the extreme points X_{jk} of S_j. Thus, any convex combination of the P_{jk} which also satisfy the first m constraints given by

$$\sum A_j X_j = b$$

for which $\sum c_j X_j$ is a minimum

will also give an optimal solution to the extremal program.

Assuming we have an initial basis for the external program which consists of columns of the form $(P_{jk}, 0, \ldots, 1, \ldots, 0)$ along with its corresponding pricing vector. We will write this pricing vector as $(w, \overline{w})$ where the m vector w is associated with the m constraints of 12.1 and the n vector $\overline{w}$ is associated with the n constraints of

12.2. Since we have a set of basis vectors for the master program this means (w, w) are such that we have

$$w\ P_{jk} + \overline{W}_j = c_{jk}$$

To determine if this is an optimal basis for the original problem, we must solve for each j the related subproblems of minimizing

$$(c_j - wA_j)\ X_j$$
$$\text{subject to } B_j\ X_j = b_j$$
$$X_j \geqq 0$$

If we now let $\overline{X}_j$ be such a solution for each j and let $\overline{X}_{jo}$ be the one for which

$$\Delta = (c_{jo} - wA_{jo})\ X_{jo} - W_{jo} = \underset{j}{\text{Min.}} \left[(c_j - wA_j)\ \overline{X}_j - \overline{W}_j\right]$$

If $\Delta = 0$ the algorithm terminates and the set of given s_{jk} solves the extremal problem and the vector

$$S_j = \sum_k X_{jk}\ s_{jk} \qquad j = 1,2,\ldots\ldots,n$$

solves the original problem.

If, however, $\Delta < 0$ we form the new column

$$(P_{jk}, 0, \ldots\ldots, 1, \ldots, 0) \text{ where } P_{jk} = A_{jo}\ \overline{X}_{jo}$$

and its associated objective function coefficient given by

$$c_{jo} = c_{jo}\ \overline{X}_{jo}$$

and introduce this column into the basis of the extremal program just as in the usual linear programming procedures.

We will not consider the decomposition of other configurations of linear programming models but will simply refer the reader to the references already cited. It is worth noting, however, that in the model we have considered we had several subproblems which were 'tied' together by common restraints. A similar block angular system results where we have several subproblems which are 'tied' together by a few common activities. It will be noticed, however, that this latter model can be solved by using the above algorithm upon the alternative dual formulation of the problem.

Some Interpretations and Potential Implications of the Decomposition Principle

It is interesting to notice how we can regard the above decomposition procedure as making use of the hierarchy of interpretations of a situation to break up the model into several submodels which are effectively related by a 'higher level' extremal program or 'master program' as it is frequently called. It seems legitimate to refer to this as a 'higher level' model since the reader will notice that the m_j restraints in each of the n submodels are replaced by a single restraint in the master program. Also, it will be noticed that the dual prices composing the pricing vector w relate to the dual value of each of the n subproblems, not as in the normal simplex procedure, to each restraint individually.

The reader will also notice that the procedure is not restricted to only two 'levels' but theoretically might be extended to deal with a large number of different levels.

The writer feels that we have in such decomposition procedures a theoretical mathematical technique which is closely allied to the procedures actually used by farmers. This is not to say that the farmers are consciously aware of the overall nature of the processes they use, but it must be admitted that there is a great similarity between the iterative-type procedures which we have noticed that farmers typically use and the way we can consider solving a linear programming model by decomposing it in this way; then, continually revising the solution by focusing first on one submodel and then on another. Also, it is the writer's opinion that the potential value of these decomposition principles in farm management advisory work do not seem to have been generally appreciated. Surely it is in such principles that we must seek the necessary theory required to fully utilize the 'bewildering array' of submodels, which, we mentioned earlier, have been formulated but, as yet, largely unused. Surely, also, we have here a procedure which might allow us to classify problem situations and the corresponding models of them so that the adviser or extension worker might utilize them to build bigger, more comprehensive models for particular situations from these smaller 'building blocks.' Also, it seems likely that the possible similarity of these submodels with the hierarchy of submodels perceived mentally by the farmer might render these procedures more acceptable to the farmer and more easily incorporated into his decision-making procedures.

IMPLICATIONS AND RESULTS FOR THE EXTENSION WORKER AND MANAGEMENT SPECIALIST

The objective for this chapter will be to concentrate upon some of the more interesting and important concepts which have arisen in the course of discussion and to emphasize the implications of these concepts in agricultural extension.

Implications of the Conceptualization of the Farmer's Mental Equipment

We have seen how a useful conceptualization of the management process as carried out by farmers is provided by the concept of a reflective goal-changing organization with a vast memory store and an extremely well-developed perceptual apparatus. The greatest inadequacies of the farmer seem to lie in his inability to carry out logical and combinatorial manipulations of the elements in his memory.

We have, also, seen that the farmer's limitations in performing these logical and combinatorial manipulations has many far-reaching implications. Thus, for example, the processes of economic development and the invention of the electronic computer, with its amazing computational abilities, are likely to motivate the existence in the future of computerized services for farmers to assist in these processes.

The computational limitations of the farmer's mental capacity can be seen to lead to more detailed and more interesting implications, however. Thus, we can see how they lead to a complex hierarchy of interpretations about elements of a problem situation and also result in farmer behavior which is somewhat less than completely rational. It follows from these two observations that we can regard the problem situation facing the farmer as two related subproblems - the consumption subproblem and the production subproblem, and in order to conceptualize the problem situation facing him, the farmer formulates a complex hierarchical structure of deterministic submodels. And, in order to build and solve these deterministic submodels, the farmer often has to make the dangerous and undesirable simplifying assumption of certainty.

Alternative Formulations of the Criterion by Farmers and Economists

It is seldom desirable that the advisory worker should concern himself with the solution of the consumption subproblem since this is normally regarded as the private domain of the farmer. However, the optimal solution to the production problem is highly dependent upon the solution to the consumption problem and for this reason we need to distinguish two ways of conceptualizing the criterion for the production subproblem.

(i) The farmer's conceptualization as a set of <u>fixed</u>

goals for production; these corresponding to the farmer's existing solution to his interpretation (or mental 'model') of the consumption and production problems he faces.

(ii) The economists or extension worker's conceptualization as a functional criterion reflecting the value to the farmer of each possible solution to the problem.

If the economist or extension worker, etc., is to be able to build and solve a model of the farmer's production problem independently of the consumption problem, he must agree upon an appropriate functional criterion with the farmer.

If an appropriate functional criterion can be developed then a mathematical programming problem results which (given the assumptions of continuity and decreasing returns) can be solved by iterative computational algorithms.

Alternative Formulations of the Problem Solving Process

It is interesting to notice how we can regard many of the algorithms as following the characteristic problem solving processes of (i) problem recognition, (ii) problem definition, (iii) problem solution, but in order to conceptualize these processes more precisely, it is suggested that they should be thought of as corresponding to the processes of (i) recognizing the inadequacy of an existing model and its solution, (ii) revising the model to account for the inadequacy, and (iii) computing the solution implied by the revised model. And, it seems this applies to both mental and 'computer' models.

The Difficulties of Problem Definition for the Management Specialist

An often recognized difficulty which is encountered in advisory work is that of an ill-defined problem. We can see, however, that this may be conceptualized as the lack of (i) structural, or, 'qualitative' specification of the implied model and (ii) numerical or 'quantitative' specification of the implied model. Also, there seems to be a complete range of 'ill-definedness' of problems from the problem which is defined neither qualitatively nor quantitatively, to the problem which is defined only qualitatively and to the problem which is defined both qualitatively and quantitatively.

It would seem to be the advisory worker's utopia that he should be provided with qualitatively defined problems by the farmer and then be relied upon to quantify the model and return the quantitative solution to him. However, this will seldom, if ever, be possible since the processes of problem, recognition, definition and solution are, theoretically at least, iterative and cyclical processes. The best that the advisory worker can hope for, therefore, seems to be a relatively well defined criterion function and some idea of the degree of detail which he should employ in building and solving his model of the problem situation.

It is important to note in this content that the process of defining a problem seems to precede that of recognizing it as one. Thus, in our linear programming example of Chapter 11, we saw how quantitatively defined data concerning other variables and restraints was necessary to be able to recognize an inadequacy in our 'model' of basis vectors.

We can see, similarly, that it is only by examining his 'past experience' and other data that the farmer can recognize a problem. This examination requires much effort, however, and it is probably for this reason that problems often go unnoticed.

We can see, also, that until the perceptual apparatus and memory capacity of computers can be improved it is unlikely that they will be of much use in recognizing and defining problems. But potentially, they seem quite capable of carrying out these processes. That is, it seems that the solution of ill-defined problems is likely to remain for many years a process requiring human involvement.

The Potential for Exploitation of the Hierarchy of Interpretations

The potential uses of the hierarchical structure of related subsets of elements commonly used by farmers (and human mental processes in general) to interpret their environment seem to hold out much potential for exploitation in computerized problem solving processes. Two such advantages provided by this structure come from (i) improvements in efficiency of storage and retrieval of data and (ii) potentialities to decompose the overall model of the problem situation into related submodels at all levels of detail. This latter advantage also seems to imply a potentiality for aggregating and making better use of the present bewildering array of submodels which have been formulated by many research and extension workers.

SUMMARY

In the earlier chapters we examined the forces underlying economic development and noted that together with the advent of the computer these are likely to motivate the existence of computerized information processing services for farmers. This is deemed sufficient reason for formulating a revised concept of the farmer's management processes as an <u>information processing organization</u>. We noted many implications of the limited capacity of the farmer to perceive and process information and the implications which resulted from the greater speed and accuracy of computers in processing information.

We then examined some of the mental procedures utilized to solve problems and the differences which seemed to exist depending upon the degree of definition surrounding the problem. Also, we noticed the way in which computers could similarly be used to solve problems, particularly well-defined ones.

In Chapter 5 we considered several formulations of the elements characterizing problem situations and developed nomenclature for use later. Then in Chapter 6 we briefly considered some of the effects of imperfect knowledge concerning the elements of a real world problem situation and some methods which are used for dealing with it. We particularly noted the simplifications and dangers arising out of the use of the assumption of certainty but, noted also, that it seems to be a common assumption used by farmers. For this reason little consideration was given to more sophisticated procedures designed to take account of risk and uncertainty.

We saw the general form of the hierarchical mental model which seems to be used by farmers in Chapter 7. Also, we considered some reasons why it should exist in this form and some of the advantages which were to be gained from it. We then saw how, as a consequence of the hierarchy of this structure, we could consider the consumption and production subproblems separately and how the existing solutions to the farmer's mental model give rise to the goals for production.

In Chapter 9 we considered the mathematical programming model as the model which described our problem situation under the assumption of certainty. We also considered how, given the assumptions of continuity, concavity and feasibility, algorithms were available which enabled its solution.

We saw how the theory about the saddle point allowed us to consider the solution to a problem as consisting of two parts, the action or 'allocation decision' and the imputed dual prices. Then, in Chapter 10, we saw how both parts were necessary to enable problems to be recognized.

It was considered worthwhile to discuss in Chapter 11 the way in which the majority of mathematical programming algorithms could be regarded as carrying out, in an iterative cyclical procedure, the processes of problem recognition, definition and solution. We saw how all three processes seemed most frequently to be inextricably intertwined since most problems recognized are ill-defined to some extent. We noted how it seemed that the processes of recognizing and defining problems could only be carried out in relation to an existing model and its solution.

In Chapter 12 we saw how the concepts we had derived allowed us to conceptualize an ill-defined problem as one which did not completely define the model it implied.

Next, having seen in Chapter 11 how the mathematical programming algorithms could only assist in structural definition of models, we refer in Chapter 13 to the processes involved in the quantitative definition of models, noting, particularly, also, the potential for using the computer to derive the quantitative data from historical data recorded via the farmer's excellent perceptual apparatus.

Finally, as a directive for further study, we briefly reviewed in Chapter 14 some work which has been done upon the principles of decomposition. We pointed out some reasons why this appears to be a fertile area for future study.

Chapter 15 was given to isolating some of the more interesting concepts which arose in the study and to indicating their implications for the management specialist.

It is hoped that the concepts developed and discussed may be of use in assisting agriculture to adjust to the forces of change which result from economic development. In particular, it is hoped that the discussion will facilitate a speedy incorporation of the innovations of operations research into the everyday managerial processes of farmers.

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