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GETTING MODELS OFF THE GROUND

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Summary

The use of the techniques of systems analysis for the first time presents particular difficulties.- This paper discusses the concept of the 'systems approach', the means of system definition and the initial stages in model building. An example of model development is given to indicate the progressive nature of this work, and this emphasises the general rule of allocating resources only as the need is established. Finally, there is a short note on team work in research, and the requirements in terms of computing facilities and data collection.

I. INTRODUCTION

Learning a new skill can be an exciting experience. It can also be a frustrating one, The traditional method of learning through observing, an expert at work has its drawbacks. For it is just as difficult for' an expert to make fundamental mistakes as it is for the beginner to avoid making them. Fortunately skills can be improved by manual and mental effort.

This paper is an introduction to the practical side of the 'systems approach'. The main concern is with the initial stages of model building, hence the title. Together with the accompanying papers by Tonnet, Rose, White and Christian *et al.* the aim of the contributors to this section of the Conference is to pass on practical experience of different aspects of systems analysis. A list of selected reading is given.

II. SYSTEMS

(a) The system approach

One way of attacking problems is to use the 'systems approach'. This operates in the following manner. For purposes of discussion and experiment a model of the problem (system) under investigation is defined. This can be a scale model, as used with wind tunnels, or it may be in a completely abstract form such as a series of mathematical equations. Models are used in problem solving and decision making in two ways. Firstly, the formal definition of the system to be studied is conducive to clear thinking and improved communication and, in many cases, gives sufficient insight into the system to indicate lines of action. Secondly, the model can be used as a basis for experiments which will predict the response of the real system. This technique is known as simulation and is particularly useful for those problems which, due to their complexity or non-linearity, are not amenable to direct analysis, or which contain elements that are subject to random

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variation. Agricultural systems have all three of these features, and for this reason simulation is a useful exploratory technique. It is, of course, only one of a band of techniques which have arisen with the growth of the discipline known as Systems Analysis. Some of these techniques are already widely used in farm management, but the general adoption of the systems approach to problem solving has been delayed, mainly by difficulties in model definition due to a lack of data, and by the difficulty of validating the model.

(b) System representation

(i) A definition

In the context of systems analysis, a system is defined as an arrangement of component parts which together perform some function. Further, the relations between the components can be functions of time and other external variables and of the values of the components. In other words the system is dynamic. From this it follows that for all except the very simple systems, the definition of the system response to all the variations in component values is a formidable task.

(ii) Some examples

Consider a simplified model of the sheep farm situation. A diagrammatic representation could be as in Figure 1 using a suggested convention.

[Fig. 1]

The first process describes the rate of reproduction, and in this simple model it is assumed that the number of lambs produced is a function of the number of ewes. This is shown by the single line entering the triangle. The lambs are either retained for future entry into the pool of ewes or are sold. Process 2 which defines the selection procedure is assumed to be a function of the number of ewes and the number of lambs. Similarly the number of weaners to be sold will be determined by information relating to the number of lambs and to the number of weaners retained.

[Fig. 2]

This model can easily be expanded to include other components. In Figure 2 the ewes are split up into different age classes. Mortality and culling effects have been introduced. This model is still a long way from reality but it serves to illustrate the interrelationships and information paths that exist in even a simplified model.

III. MODEL BUILDING — THE INITIAL STAGES

(a) The aim

The first step in model building is to define the purpose and scope of the model in relation to the overall problem. This will determine the scale or level of the model. For example, the production of herbage could be regarded on a per hectare basis or at the level of intercellular activity. Although the real system includes all levels of processes and quantities, the model will be an abstraction to some particular level. The choice of the level then determines the components which are to be included in the model, and it also indicates the relevant forcing functions (inputs) and the data required for them.

It is at this point that the quantities in the system will be seen to fall into several distinct groups. Some, like hours of daylight, will be variable but will be

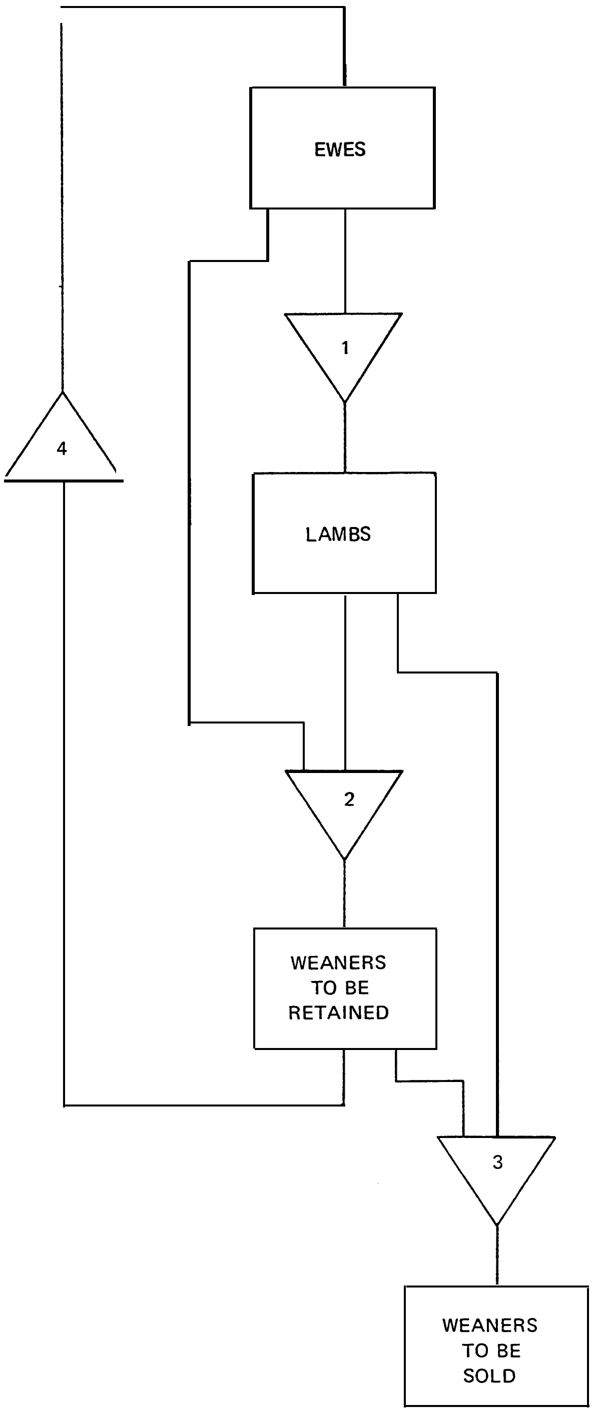

Fig. 1. — A simple system of quantities, processes and the associated information paths.

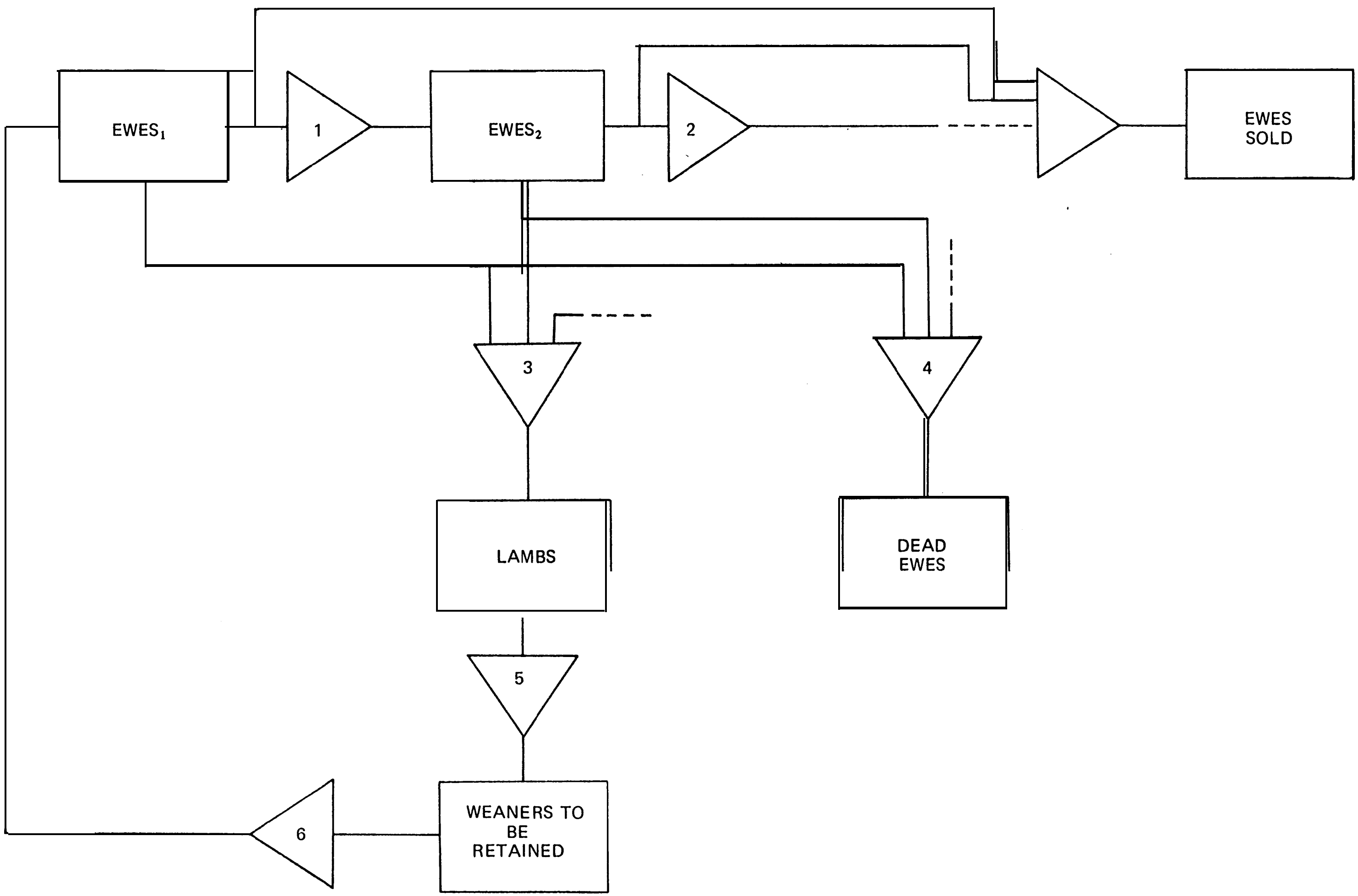

Fig. 2. — The Ewes are separated into different categories according to age to cater for lambing and mortality processes.

known accurately. Others, while having a constant value, will only be known approximately. Other variables such as rainfall will be subject to random variation and this randomness may be an essential part of the model. As a general rule however, in the initial stages the model should incline towards simplicity and reasonableness rather than complexity and realism. The introduction of stochastic (random) variables at the beginning will only obscure the main aim which is to construct a feasible model.

(b) Draft and block diagrams

The next stage, assuming a simulation model is to be used, is to draw up a draft diagram of the model. This will show the basic quantities (ewes, green feed, labour, capital) and the processes by which they are connected.

The thing to avoid at this stage is to call a halt to modelling while everyone busies themselves recording measurements on all the unknown processes. Instead, the processes should be defined in an empirical way using the data and estimates of people experienced with the problem. Then translate the block diagram into a computer program and run this version of the model. After correcting any gross errors the model should be run with variations in those parameters considered to be dominant. The results will show how responsive the model is to these changes and this will strengthen or throw doubt on your initial assessment. In any case you should now concentrate on those parts of the model which appear to have the most effect. It may mean expansion of the block diagram, a literature search or the setting up of field and laboratory trials. The point is that the model is refined, and research resources allocated only as and where the model is shown to be inadequate for its purpose.

IV. DEVELOPING A MODEL

There is always a danger when looking at the final product that the stages leading up to it will be discounted. It is not unknown for the early practitioners to do this, probably out of a sense of guilt that their early efforts were (as it now appears) so crude. This effect is particularly relevant with models which are bound to pass through many revisions in their development. The following section describes the development of a particular process in a model of a grazing system.

(a) Eating

A model of a grazing system (Freer et *al.* 1970) has been developed sporadically since 1967. One particular and important process is the reduction in the available pasture by the sheep eating it.

In the original model the only representation of pasture was by dry material. Intake ‘was simply proportional to availability until an upper limit to intake was reached.

In the next development rain produced green material, and as this aged it passed through a succession of digestibility classes until a residual quantity was added to the pool of dry material. At first, the intake of food was calculated (Table 1, Equation 1) from the total material available and the mean digestibility of the selected diet. To predict the latter value, the proportion of green in the

TABLE 1

Equations ***used to calculate the*** *food eaten by* ***sheep***

		Equation No.
IA	$= IU\ [1-e^{-a(G+D)}].Y$	1
PGE	$= 1.0-e^{-bP}$	2
IPG	$= 1.0-e^{-cG^2}$	3
IPD	$= (IU-IPG)\ (1.0-e^{-hD^2})$	4
$\frac{d(IPG)}{dT}$	$= j(G-IPG)\ (IU-IPG)$	5

Key:

D	weight of dry material (kg/ha)
G	weight of green material (kg/ha)
IA	actual intake (kg/sheep/day)
IU	upper limit of intake (kg/sheep/day)
IPD	potential intake of dry (kg/sheep/day)
IPG	potential intake of green (kg/sheep/day)
P	proportion of green in food available
PGE	proportion of green in diet selected
T	time from start of day's grazing
Y	digestibility of selected diet
a,b,c,h,j	are constants

diet was calculated (Equation 2) as a function of the proportion of green in the available food, and the mean digestibility was the weighted mean of the components, biased upwards in proportion to the amounts available to allow for selective grazing. -However, the predicted proportion of green in the diet was insensitive to the absolute amounts of green and dry if these changed in proportion.

To overcome this,. the sheep were considered to be satisfying their appetite successively from the green and dry material. A change in the intake of green with respect to its availability was proportional not only to its availability but also to the extent to which the animals' potential intake of green had not already been satisfied. Integrating this function gives the potential intake of green (Equation 3), and this value was taken from the appetite of the animals before calculating the potential intake of dry in the same way (Equation 4). The actual amounts eaten were calculated by multiplying the potential values by the digestibility coefficients.

The most recent development is to allow for both reduction in hunger and reduction in avaiiability during each day's grazing. Thus the rate of potential intake is given by Equation 5.

There are two lessons which emerge from this and similar work. They concern relations and data.

Consider firstly, the relations used in this part of the model. As our experience in modelling increased, and as we found the proposed equations had deficiencies, so the equations have been refined. From a simple description we have developed this part of the model to the point where the mathematical equations approach biological reality.

Secondly, although the supporting data was neither detailed, generalized, or precise, it did not impede model development. We will almost certainly find it necessary to undertake experiments to obtain better data for these relationships, but before we do the need must be seen to exist.

V. REQUIREMENTS FOR MODELLING

The application of systems analysis techniques to agricultural problems is itself a problem in resource allocation. There is some need to evolve special skills, to use specialised equipment, and the scope of most models requires a cooperative effort by -a team.

(a) The team approach

Whilst a group of experts may be necessary to cover all aspects of a problem, there is also an enhancement effect of working in a team because interaction in discussion plays an important part in the integration of the components of the system.

Projects handled by teams do require resources to be allocated to the organizational aspects. These are mainly concerned with communication. There is a definite need to issue regular reports on the projects and for formal contact between groups doing similar work.

(b) Special equipment

There are two categories to be considered, equipment to aid the modelling phase and equipment for the field or laboratory.

Special equipment for the modelling phase means computers. The minimum requirements are easy access to the computing system and the availability of a higher level programming language such as Fortran or Algol. There are many desirable extras. For example, special purpose programming languages such as Simscript, CSMP and Dynamo have their place. Simscript is a powerful simulation language designed for discrete applications. It is particularly valuable in problems where the scheduling and cancelling of future events has a complex structure.

For the user whose problems are defined in terms of differential equations,, languages such as CSMP (see the paper by M. L. Tonnet) or Dynamo are suitable.

The beginner, however, is advised to use the local common language which will normally be Fortran or Algol. The main reason for this advice is the ease in obtaining instruction and debugging facilities.

Some specialist languages are restricted to a particular computer manufacturer, and limitations of this sort can inhibit communication between groups using different computing systems.

There have been several investigations into the suitability of existing languages for simulation purposes (Brennan and Linebarger, 1964; Clancy and Fineberg, 1965; Charlton, 1971), the comparison of languages (Tocher, 1965; Teichroew and Lubin, 1966) and proposed languages (Krasnow and Merikallio, 1963; Kiviat, 1966).

Then there are special input-output devices which enable the user to communicate directly with his model. Using graphical output, a simulation model can be manipulated in the same way as an ordinary laboratory experiment. The user can view the effect of different parameter settings in the model or of different model layouts, and thus gain insight into the overall model behaviour.

As a result of initial work in the modelling phase it is frequently found that there are certain key elements in the model. At the same time it is found that these key elements are lacking good data. This leads to further experiments and it may also require special equipment. One of the usual requirements is to sample a particular variable intensively. This could involve automatic data collecting. The contribution by Dr. Rose will describe some experience with this type of equipment.

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