TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE 26, 375-388 (1984)

MISS-E: A Method of Modeling and Simulation of Dynamic Systems

HALINA KWASNICKA and WITOLD KWASNICKI

ABSTRACT

The MISS-E computer program is a method for the modeling of continuous dynamic systems. This paper provides a general description of the program with special attention given to the inclusion of events into the model. Events may interact with continuous variables and also may influence the structure of the model. The model is constructed by interacting with the program.

Introduction

This paper presents an approach to modeling continuous, dynamic systems. The method was developed especially for modeling socio-economic systems, hence the name MISS-E from the Polish abbreviation for Interactive Modeling of Socio-Economic Systems. The simulation experiments reveal, however, that this method may also be successfully applied to the modeling of engineering systems and to solving ordinary differential, difference, and mixed difference-differential equations.

The authors had two general purposes for developing MISS-E:

1. The inclusion of events into the mathematical description of the process being modeled;
2. An incorporation of the main virtues of J. Forrester's Systems Dynamics [2], as well as those of the methods of structural modeling [7, 8], such as QSIM [10], and KSIM [4].

The approach used in MISS-E to incorporate the modeling of events into models of continuous systems differs from those proposed by Gordon and Stover [3], Lipinski and Tydeman [9], and Enzer [1]. In MISS-E, the occurrence of an event can influence:

1. The values of continuous variables,
2. The probabilities of occurrence of other events, and
3. The structure of the model.

The influence of values of continuous variables on probabilities of events can be

HALINA KWASNICKA and WITOLD KWASNICKI are with the Futures Research Center of the Technical University of Wroclaw, Wroclaw, Poland.

Address reprint requests to Dr. Witold Kwasnicki, Forecasting Research Center, Technical University of Wroclaw, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland.

 0040-1625/84/$03.00

considered. The imposition of logical conditions on the occurrence of events is also possible. For example, event A may occur only after the occurrence of events B and C. Variables which describe the behavior of the modeled process are divided in MISS-E into two classes, as they are in DYNAMO and QSIM. These two classes are:

1. *State variables* (i.e., accumulating variables). These variables are "levels" in the DYNAMO notation [2] (e.g., nonrenewable resources and industrial capital). They are in complete accord with the concept of the state variable as defined in systems theory.
2. *Auxiliary variables* (i.e., variables which are functions of the state variables).

Either state or auxiliary variables may belong to one of four categories:

1. *"Quantitative" variables* (i.e., variables without any constraints on their variability).
2. *"Qualitative" variables* (i.e., variables whose values belong to a finite set of real numbers). This category makes it possible to use subjective or intuitive variables. These would include, for example, the quality of life in Poland or the convenience of public transport in Wroclaw. Values of such variables may not be measured by an objective method. The only way to "measure" these variables is via subjective methods such as public inquiry. The range of variability is assumed, for instance, from 0 to 100, and the initial or Delphi value of the variable can be obtained by averaging the answers from a survey.
3. *Recurring events* (i.e., events which may occur more than once during the simulated period, such as an ecological catastrophe or a workers' strike).
4. *Nonrecurring events* (i.e., events which may occur only once during the simulated period, such as EEC and COMECON's establishment of a single free trade bloc).

The functional form of an auxiliary variable may consist of:

1. Function of the state or other auxiliary variables;
2. A time-dependent function, such as an input variable;
3. A time-delayed function of the state or the auxiliary variable;
4. The derivative of the state or auxiliary variable.

In DYNAMO, the flow diagrams are used to portray the structure of the model constructed. This is very effective in large models. Small and medium-size models, on the other hand, use interactive matrices to show the structure of the model (as in QSIM and KSIM). Both methods of representation are available in MISS-E.

The most expensive and time consuming stages of the model building are:

1. Translation of the mathematical model into a computer model, which involves writing the algorithm in a computer language and obtaining a correct program compilation;
2. Simulation of the computer model (i.e., testing the assessment of sensitivity and utility, and experimenting with possible alternative policies).

To make these two stages most effective, the ALGOL 1900 program called MISS-E operates in a conversational mode. Nearly all information about the model is given to this program in the form of parameters. Only functional forms of auxiliary variables have to be written in ALGOL or FORTRAN languages by the modeler. This allows for flexibility in the programming possibilities of the algorithmic languages.

Other features of MISS-E include:

1. A very general equation form similar to that used in DYNAMO; for example, a set of ordinary first-order differential equations may be used while DYNAMO's "inrate" and "outrate" variables are eliminated.
2. MISS-E prints meaningful time scales on its output, as do DYNAMO and QSIM.
3. As with QSIM and KSIM, the modeling process may be operated by people with little knowledge of computers.
4. Changes of simulated conditions, such as the structure of the model or the interactions among variables, are possible at any stage of the experiment. It is also possible to force the occurrence of events at any point in the simulation.

The Modeling Process

This section identifies the problem, specifies the model's purpose in terms of the dynamic system behavior to be explained, and establishes the temporal and spatial boundaries. For a fuller discussion of the modeling process, see Kwasnicka and Kwasnicki [5]. The following discussion uses as an example a simplified model of plant production. A fuller model of the agricultural sector is presented in Kwasnicka and Kwasnicki [6].

VARIABLES AND THE STRUCTURE OF THE MODEL

All variables in MISS-E may belong to one of the four categories defined in the introduction: quantitative variables, qualitative variables (scope = 0,100), recurring events, and nonrecurring events.

At any time t, quantitative and qualitative variables may be characterized by their values at time t; and events may be characterized by their probabilities of occurrence during the period $(t, t + 1)$, i.e., during the next chosen unit of time. The reciprocal of the probability is approximately equal to the average time until the event will occur.

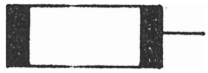
As a first step toward working out the structure of the computer model, the causal relationships (which form the basis for building the flow diagram) and the feedback loops must be described. An example of this can be seen in the causal structure for the agricultural sector as shown in Figure 1.

Before the flow diagram can be built, the designer must select specific variables to take the role of state variables, and others to play the part of auxiliary variables. While there are no absolute rules regarding how this determination should be made, it should be remembered that state variables represent the cumulative variables and auxiliary variables are functions of the state variables. An auxiliary variable may be:

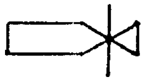
1. Any function of a state variable,
2. A time-dependent function,
3. A time-delayed state or auxiliary variable,
4. A derivative of the state or the auxiliary variable, or
5. Any function combining the above four types.

The flow diagram has eight main components, which are very similar to those used in DYNAMO:

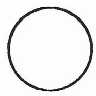
Level/state variable—represents quantitative and qualitative variables.



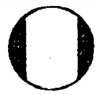
Level for event—i.e., the probability of the event's occurrence as a state variable.



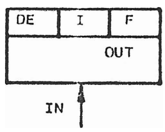
Rate of change of the state variable.



Auxiliary variable.

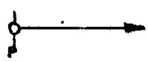


Event as an auxiliary variable.



Delaying of variables IN; in the area OUT is written the variable in which the value of the time-delayed variable IN is stored. Areas DE, I, and F are respectively for the delay number and numbers of the initial and final parameters.

Functional relationship between two variables.



Functional relationship of the parameter P and an auxiliary variable.

Short descriptions for variables, codes, and statements describing the mathematical form of the variables are written in these graphical symbols for both state and auxiliary variables. A flow diagram for the model used in our example is shown in Figure 2. In regard to the flow diagram, the following need particular note:

1. State variables are designated in succession by Y1, Y2, etc.
2. Auxiliary variables whose values may be printed as output results during simulation are designated by A1, A2, A3, etc.
3. Auxiliary variables which influence rates of state variables must be designated by A due to the way in which the MISS-E computer program is organized.

The functional form of the auxiliary variables (and *only* the functional form) must be written in computer language. Following are some of the essential principles for the writing of these functional forms:

1. All names are written in capital letters and time is designated by *T*.
2. Arithmetic functions are written as follows: addition, +; subtraction, −; multiplication, *; division, /; and standard functions, ABS, LN, SIGN, SIN, COS, EXP, ENTER.
3. Equivalence between a variable's symbol and its mathematical form is designated by a colon and an equal sign—e.g., P{20} : = EXP(− 5*T);. The end of the mathematical form is signified by a semi-colon.

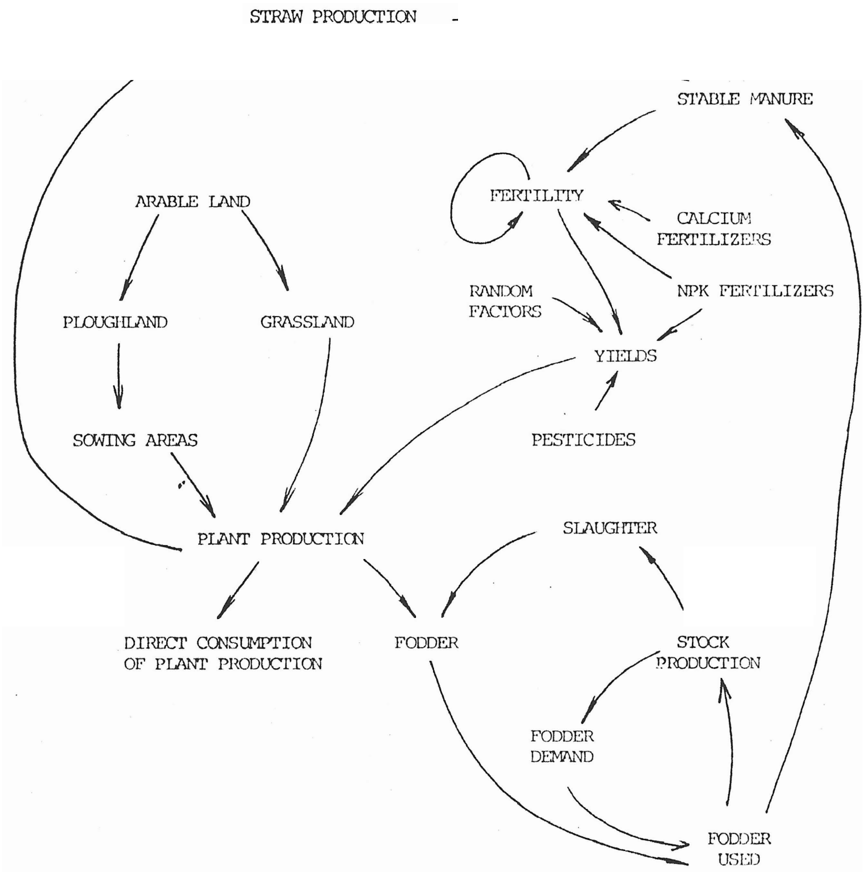


Fig. 1. Causal structure of agricultural sector.

4. Piecewise linear functions are available in MISS-E and are denoted by FUN. This function (for example, see Figure 3) is fully determined by the coordinates of its bend points and is indicated by our function points A, B, C, D, E. The coordinates of MISS-E are given as "auxiliary parameters" and are designated in succession by P{1}, P{2}, P{3}, etc. The function in Figure 3a may be written in MISS-E as:

   A{2}: = FUN(Y{13}, 9, 18);

   The first parameter of FUN is the argument of the piecewise linear function, which may be an expression of any variable. The second and third parameters describe the initial and final numbers of auxiliary parameters which describe the function. In the present case, the parameters from 9 to 18 must equal:

   P{9} = 0, P{10} = 1, P{11} = 1, P{12} = 2, P{13} = 3, P{14} = 2, P{15} = 5, P{16} = 4, P{17} = 6, and P{18} = 4.5.

   The first two parameters describe the coordinates of point A, the third and fourth describe the coordinates of point B, etc. Thus, the step function shown in Figure

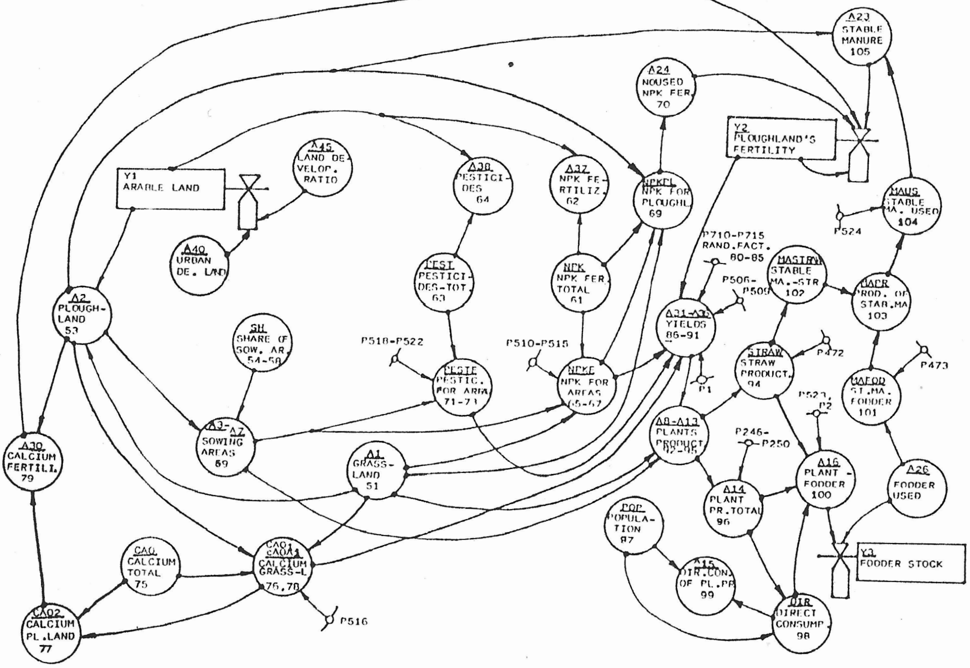


Fig. 2. Flow diagram of plant production model.

3b may be described as

$$B\{1\}: = \text{FUN}\ (T,\ 1,\ 8).$$

The auxiliary parameters are

$$P\{1\} = 0,\ P\{2\} = 0,\ P\{3\} = 5,\ P\{4\} = 0,\ P\{5\} = 5,$$
$$P\{6\} = 1,\ P\{7\} = 10,\ \text{and}\ P\{8\} = 1.$$

5. The time delayed function is described as LAG. If, for example, auxiliary variable A5 at time T is equal to the value of variable Y10 at time T – 4, 5 (delay is

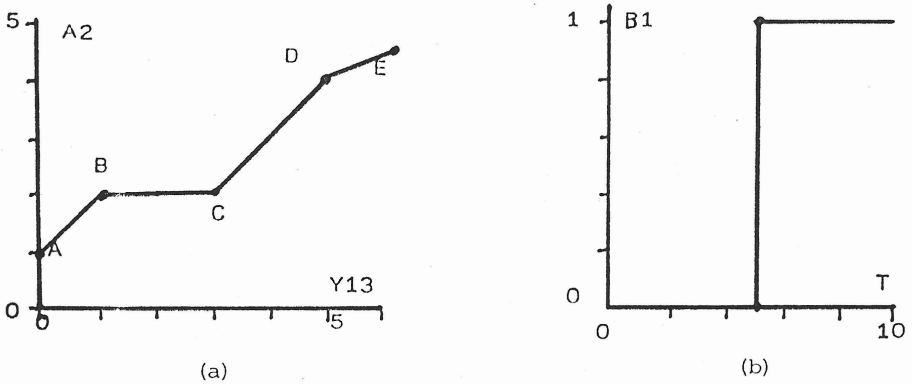


Fig. 3. Piecewise linear functions.

equal to 4, 5 units), then it may be expressed as A{5}: = LAG (SV, 10, 2, 21, 28) where:

a. The first parameter informs about the type of delayed variable and is equal to SV (where the delayed variable is a state variable) or AV (where the delayed variable is an auxiliary variable)
b. The second parameter is equal to the number of the delayed variable
c. The third parameter is equal to the number of the delay. The sequence of delays is given as input data (e.g., 3, 4.5, 2, 5, 1); the number of the appropriate elements in the sequence is also given. To begin the simulation run with a model that contains delayed variables, it is necessary to use the values of the delayed variables before the initial moment. These values are presented as piecewise linear functions. The fourth and fifth parameters are equal to the initial and final auxiliary parameters P.

6. Derivatives of state and auxiliary variables are described by a D function. For example, the derivative of the auxiliary variable A {5} may be written as A{4} : = D (AV,5). Here, the first parameter tells us about the type of variable whose derivative must be reckoned and is equal to SV for the state variable and AV for the auxiliary variable. The second parameter is equal to the number of the variable.
7. Generation of random numbers with uniform distribution of (0,1) is designated by GEN. The random value is stored in X, and successive random values are generated by GEN(X);. The GEN procedure allows generation of random values with other distributions.
8. All other procedures initiated by the modeler may be incorporated during the time the functional form of the auxiliary variables is defined.

Table 1 presents the equations for the auxiliary variables. Statements 49 and 50 define the local variables, the values of which are never printed in the simulation output. Some of these variables, HE, for example, provide an effective means of reckoning the values of certain other variables (see statements 65-72). The instructions FOR and IF are used in the description of some of the variables enabling the modeler to use short, and yet effective, notations.

TABLE 1
Equations for Auxiliary Variables in the Plant Production Model

```
49  'REAL' NPK,PEST,CAO,CAO1,CAO2,CAOA1,POP,STRAW,DIR,
50  HE,NPKPL,MAFOD,MASTRAW,MAPR,MAUS,MAPOT;
50
50  'ARRAY' SH,PESTF[1:5],NPKF[1:6];
51
51  'COMMENT' GRASS-LAND,PLOUGHLAND AND SOWING AREAS COMPUTATION;
51  A[1]:=FUN(T,18,25);
53  A[2]:=Y[1]-A[1];
54  SH[5]:=1;
55  'FOR' I:=0 'STEP' 1 'UNTIL' 3 'DO'
56  'BEGIN'
56  SH[I]:=FUN(T,26+I*8,33+I*8);
58  SH[5]:=SH[5]-SH[I]
58  'END';
59  'FOR' I:=3 'STEP' 1 'UNTIL' 7 'DO' A[I]:=SH[I-2]*A[2];
61  'COMMENT' FERTILIZERS AND PESTICIDES FOR SOWING AREAS;
61  NPK=FUN(T,58,69);
62  A[37]:=NPK/Y[1];
```

```
PEST: = FUN(T,70,81);
A[38]: = PEST/Y[1];
HE: = P[510]*A[1] + P[511]*A[3] + P[512]*A[4] +
P[513]*A[5] + P[514]*A[6] + P[515]*A[7];
HE: = NPK/HE;
'FOR' I = 1 'STEP' 1 'UNTIL' 6 'DO' NPKF[I]: = HE*P[509 + I];
NPKPL: = (NPK - NPKF[1]*A[1])/A[2];
A[24] = FUN(NPKPL,474,481);
HE: = P[518]*A[3] + P[519]*A[4] + P[520]*A[6] + P[521]*A[6] + P[522]*A[7];
HE: = PEST/HE;
'FOR' I: = 1 'STEP' 1 'UNTIL' 5 'DO' PESTF[I]: = HE*P[517 + I];
CAO: = FUN(T,82,93);
CAO1: = CAO*A[1]/(A[1] + A[2]*P[516]);
CAO2: = CAO - CAO1;
CAOA1: = CAO1/A[1];
A[30]: = CA02/A[2];

'COMMENT' RANDOM FACTORS GENERATION;
'IF' T'GE'P[16] 'THEN'
'BEGIN'
P[16]: = P[16] + 1;
'FOR' I: = 1 'STEP' 1 'UNTIL' 6 'DO'
'BEGIN'
GEN(X); P[709]: = FUN(X,626 + I*12,637 + I*12)
'END'
'END';

'COMMENT' YIELDS OF GRASS,GRAIN,POTATOES,SUGAR-BEETS AND OTHER;
A[31]: = P[1]*FUN(NPKF[1],94,105)*FUN(CAOA1,106,117)*P[710];
A[32]: = Y[2]*FUN(NPKF[2],118,129)*FUN(PESTF[1],130,141)*P[711];
A[33]: = Y[2]*P[506]*FUN(NPKF[3],142,153)*FUN(PESTF[2],154,165)*P[712];
A[34]: = Y[2]*P[507]*FUN(NPKF[4],166,177)*FUN(PESTF[3],178,189)*P[713];

A[35]: = Y[2]*P[508]*FUN(NPKF[5],190,201)*FUN(PESTF[4],202,213)*P[714];
A[36]: = Y[2]*P[509]*FUN(NPKF[6],214,225)*FUN(PESTF[5],226,237)*P[715];

'COMMENT' PLANTS PRODUCTION,TOTAL PLANT PRODUCTION,DIRECT CONSUMPTION,
        PLANTS PROD. FOR FODDER;
'FOR' I: = 0 'STEP' 1 'UNTIL' 4 'DO' A[8 + I]: = A[32 + I]*A[3 + I];
STRAW: = A[8]*P[472];
A[13]: = A[31]*A[1];
A[14]: = A[8] + A[9]*P[246] + A[10]*P[247] + A[11]*P[248] + A[12]*P[249] +
A[13]*P[250];
POP: = FUN(T,238,245);
DIR: = A[14]*FUN(A[14]/POP,482,489);
A[15]: = DIR/POP;
A[16]: = A[14] - DIR + STRAW*P[523]*P[2];

'COMMENT' PRODUCTION OF STABLE MANURE;
MAFOD: = A[26]*P[473];
MASTRAW: = STRAW*(1 - P[523])*P[565];
MAPR: = 'IF' MAFOD)MASTRAW 'THEN' MASTRAW 'ELSE' MAFOD;
MAUS: = MAPR*P[524];
A[23]: = MAUS/A[2];
```

The model presented in this paper demonstrates another possible way of incorporating random processes into a model. It is assumed, for example, that yields per hectare depend upon random factors. The values of the random factors are drawn once per year at the beginning of the year; the time of the drawing is determined by parameter P{16}. (Statements 80–85 indicate one possible system of notations for the random factors.)

First, the random numbers of the uniform distribution of (0,1) are generated (statement 83). Next, the values of the random factors for all plants are determined (based on the numbers generated in step 1 and on the inverse function of distribution). These inverse functions are presented as piecewise linear functions (shown in Figure 5d). The values of the random factors are stored in the auxiliary parameters P{710} to P{715}.

The next step is to determine which functions are interaction functions (that is, which functions influence rates of change for the state variables). They are plotted as piecewise linear functions. Their values are then summed, yielding the overall effect of the change. As Appendix 1 demonstrates, this additive mode does not diminish the generality of the approach.

The influence of four specific types of interaction functions requires special elaboration:

1. *The influence of the quantitative variable Y1 on the rate of change of the quantitative or qualitative state variable Y2.* The interactive function is established by repeatedly asking a question such as: "If at any time, the value of Y1 = y1 and the influences of the other variables are equal to zero, what would be the rate of change of y2?"
2. *The influence of either a recurring or nonrecurring event on the rate of change of the quantitative or qualitative state variable.* The influence of the event is visible only *after* its occurrence. This type of function shows the state variable's rate of change (assuming the influence of other variables is equal to zero) at time after occurrence = *t*. An example of this type of function is shown in Figure 4c.

In both types 1 and 2, the influence may not rest squarely on the rate of change, but rather on the *relative* rate of change (see Figures 4b and 4d).

3. *The influence of the quantitative or qualitative variable, Y1, on the probability of the event's occurrence.* This type of function demonstrates the dependency

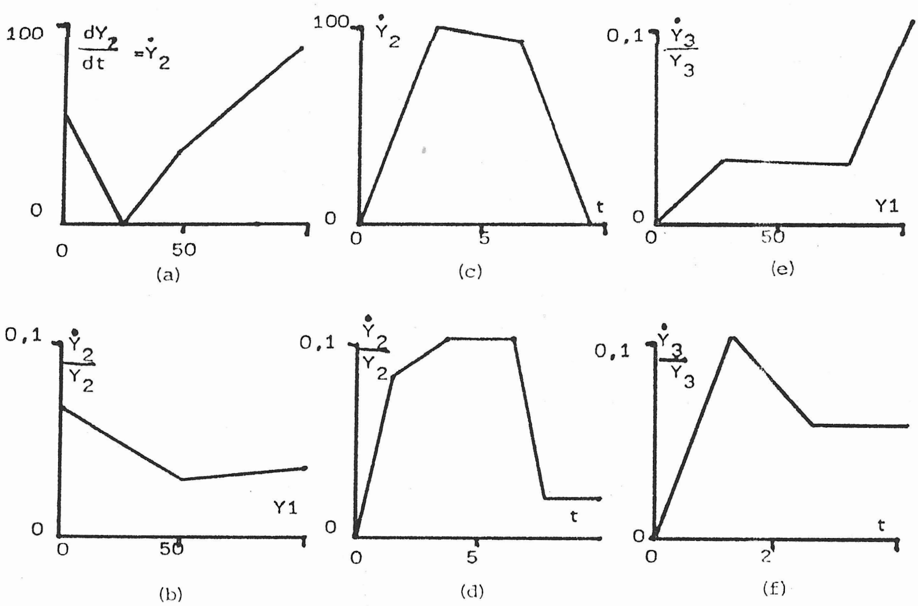


Fig. 4. Interaction functions.

of the relative rate of change in probability on the values of the influencing variables (when the influence of other variables is equal to zero). (See Figure 4e.)

4. *The influence of the event on the probability of occurrence of another event.* This type of function shows how the relative rate of probability change depends on the time after the moment of occurrence of the influencing event. (See Figure 4f.)

The piecewise linear functions used in the equations for auxiliary variables and interactive functions in our examples are shown in Figure 5.

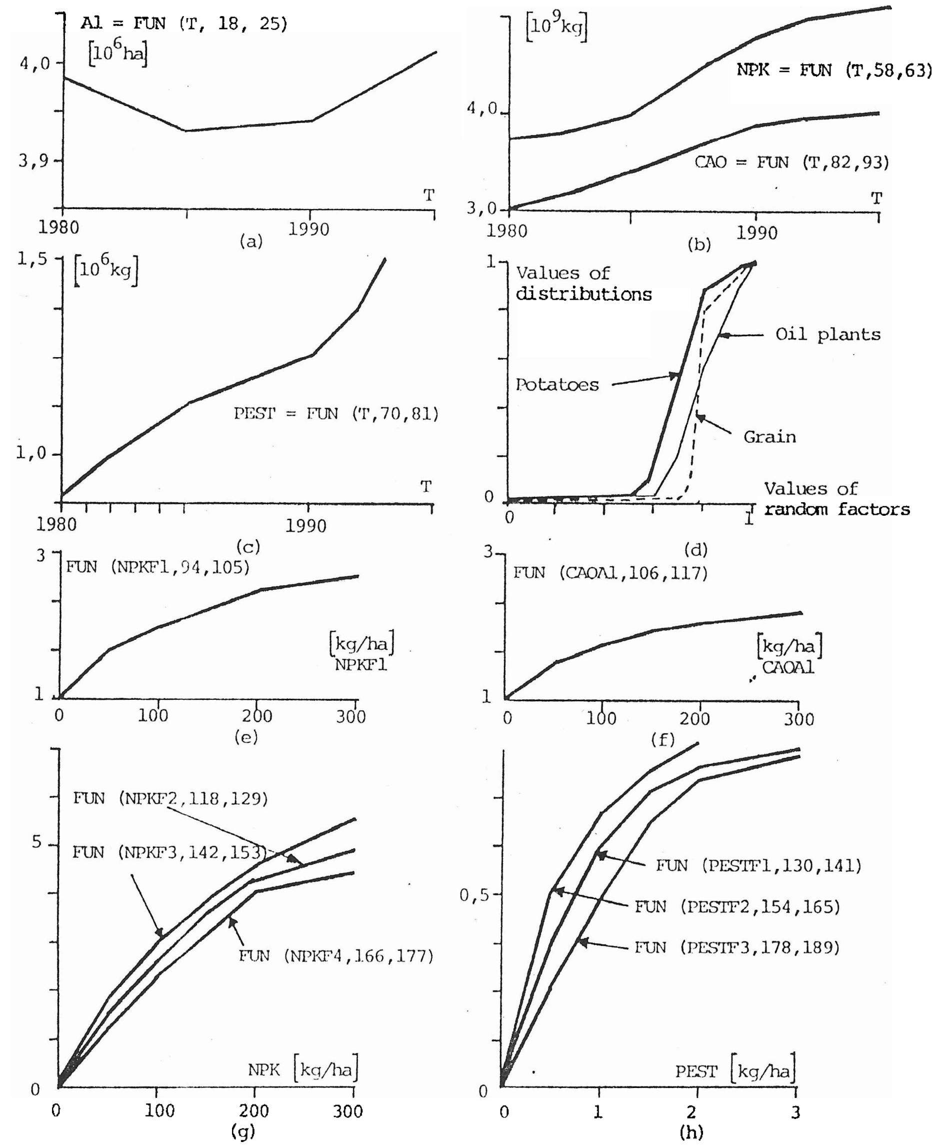


Fig. 5. Functions in the model: (a) grassland; (b) NPK and calcium fertilizers; (c) pesticides; (d) distribution of random factors in yield function; (e)–(h) fertilizer and pesticide functions; (i) direct consumption of plant production; (j) plants not using NPK fertilizers; (k)–(p) interaction functions.

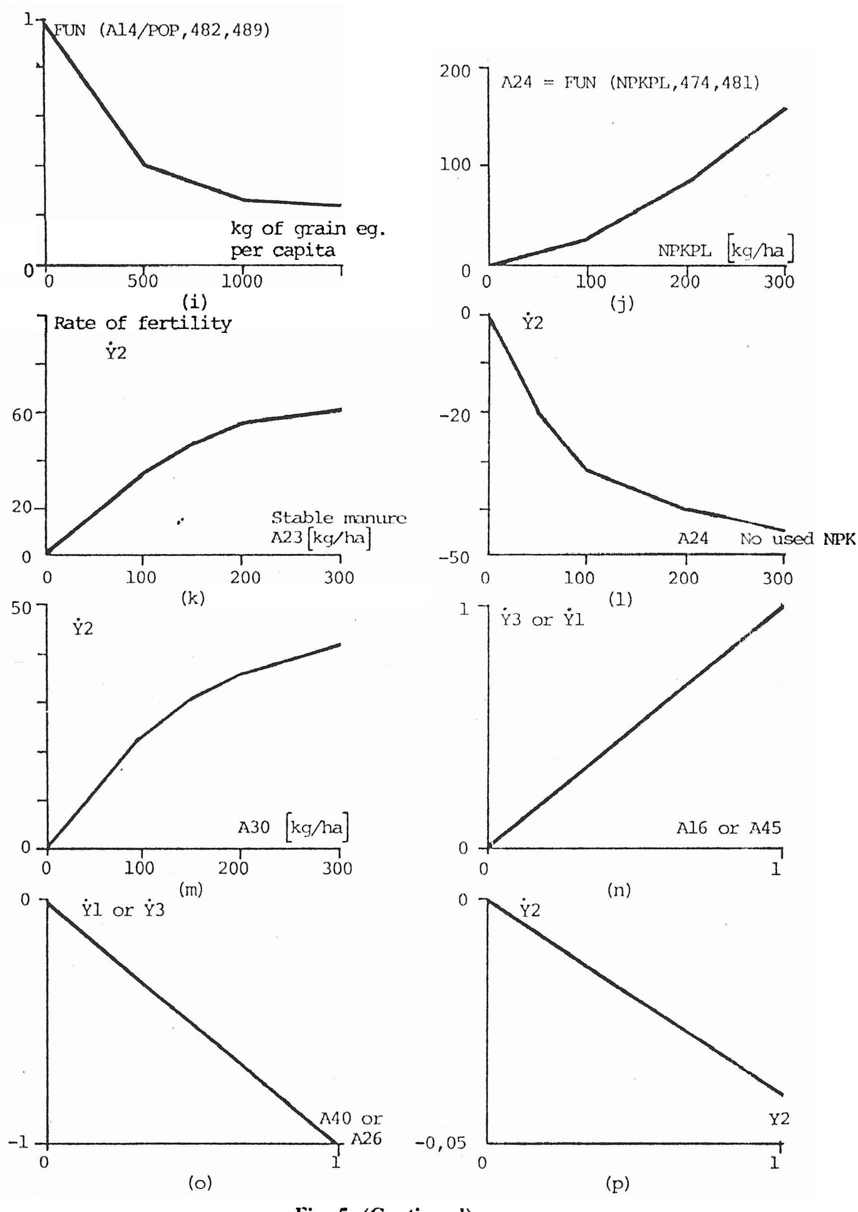


Fig. 5. (Continued)

After the functional forms of auxiliary variables are written into the computer, the true conversation with MISS-E begins. During this conversation, all information established in the previous steps is written directly on the terminal or is drawn from the indicated files. At any stage of the simulation it is possible to change the model's structure. New interactions may be added, for example, or an existing interaction function may be withdrawn. The shape of the existing interaction functions, the values of the state variables, the values of the delays, and the method and steps of integration also may be changed. It is also possible to force the occurrence of some events at any stage, which makes possible the generation of scenarios.

As with DYNAMO, results may take the form of tabular and/or graphical output at any stage of simulation. The results of one simulation experiment are shown in Figure 6.

Concluding Remarks

MISS-E has been applied as a structural modeling tool in the building of both small and large models, and the results are promising. The approach seems to be convenient for generating and searching for crucial points in the development of systems scenarios.

The use of codes for the state variables and auxiliary variables and the definition of the auxiliary variables in terms of an algorithmic language (FORTRAN or ALGOL) allows MISS-E to be applied to a wide range of systems. We recognize, however, that there are instances where generality is not needed. In such instances, the definition of the variables by code may cause errors and confusion. Instead, we suggest that the user employ short, meaningful acronyms rather than codes, as in the QSIM2 approach.[1]

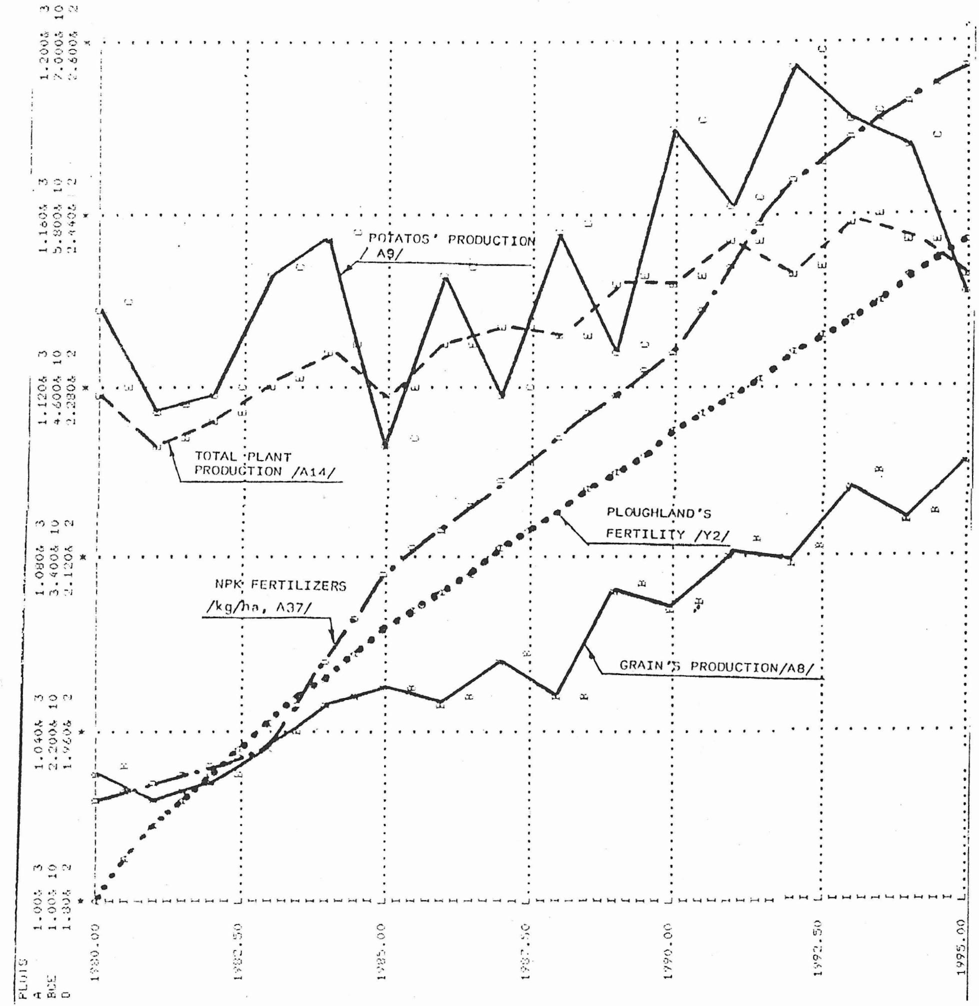


Fig. 6. Graphical output of MISS-E.

[1]This improvement was the suggestion of Dr. Wayne Wakeland, Portland State University, Systems Science Department. We are grateful for his helpful suggestions and comments.

Future MISS-E development is projected to include the incorporation of a procedure for selecting the most probable scenario(s), the optimization of a model's parameters, and a procedure for sensitive analysis.

Appendix 1: The Mathematical Foundation of MISS-E

Before developing MISS-E, the authors made the following assumptions:

1. The developed method must enable modeling of as wide a range of continuous dynamic systems as possible;
2. The time necessary to implement the constructed model must be short;
3. The developed method must provide great flexibility in terms of changing the model's structure and parameters during the simulation.

The greatest concern was with the first assumption: the need to utilize a general mathematical model which could be used to represent a large class of systems. The model selected is a set of first order ordinary differential equations of the type:

$$\frac{dYi}{dt} = F_i(Y_1, Y_2 \ldots Y_s),$$

where $i = 1, 2, \ldots s$.

In order to satisfy the above assumptions, some restrictions have been placed on the form of $Fi(\overline{Y})$; however, the restrictions do not in any way limit the generality of MISS-E. Using adequately defined auxiliary variables, it is possible to model nearly every kind of ordinary differential equation.

For quantitative state variables,

$$\frac{dYi}{dt} = \sum_{j=1}^{n} F_{ij}(Y_j) + \sum_{k=1}^{k} G_{ik}(A_k) + \sum_{l=1}^{p} E_{i1},$$

where F_{ij}, G_{ik}, and E_{i1}, respectively, are the interaction functions of Y_j, A_k, and event 1 on $\frac{dYi}{dt}$.

For qualitative state variables,

$$\frac{dYi}{dt} = \left(\sum_{j=1}^{n} F_{ij}(Y_j) + \sum_{k=1}^{k} G_{ik}(A_k) + \sum_{l=1}^{p} E_{il}\right) \times B \times (100 - Y_i) \times Y_i.$$

For events:

$$\frac{dpi(t)}{dt} = \left(\sum_{j=1}^{n} F_{ij}(Y_j) + \sum_{k=1}^{k} G_{ik}(A_k) + \sum_{l=1}^{p} E_{il}\right) \times C \times (1 - pi) \times pi,$$

where $pi(t)$ = the probability of the event's occurrence during the period $(t, t + 1)$.

The arbitrarily chosen mathematical forms of the normative function in equations for qualitative state variables ($B_x(100 - Y_i) \times Y_i$) and for events ($C_x(1 - Pi) \times Pi$) require special elaboration. The choice of these forms has been imposed on the one hand by the necessity of ensuring the variability of these variables within their range, and on the other, to diminish the deformation of the experts' answers (i.e., the sums of interaction functions F_{ij}, C_{ik}, and E_{il}).

Many possibilites exist in the choice of functions. For example, Kane [4] has assumed the normative function equal to $-Y_i \times \ln(Y_i)$. Our normative functions are very similar to the functions in differential equations for the logistic (*S*-shaped) function which is often used to describe social and technical processes. (A more detailed discussion of normative functions may be found in Kwasnicka and Kwasnicki [5]).

During the numerical integration, pseudo-random variables are generated; and on the basis of these variables, the occurrence or nonoccurrence of events is determined. In MISS-E, the complex exponential distribution of waiting time on the event's occurrence T has been assumed. Thus,

$$F_i(T) = 1 - \exp(-\lambda i(t) \times T),$$

where $\lambda_i(t)$ = the stochastic process. The values of $\lambda_i(t)$ are reckoned on the basis of the probability of the event's occurrence during the period $(t, t + 1)$.

References

1. Enzer, S. INTERAX—An interactive model for studying future business environments. *Technological Forecasting & Social Change* 17:141–160, 211–242 (1980).
2. Forrester, J. W. *Principles of Systems*. Wright-Allen Press (1968).
3. Gordon, T. J., and Stover, J. Using perceptions and data about the future to improve the simulation of complex systems. *Technological Forecasting & Social Change* 9:191–212 (1976).
4. Kane, J. A primer for a new cross-impact language—KSIM. *Technological Forecasting & Social Change* 4:129–142 (1972).
5. Kwaśnicka, H. and Kwaśnicki, W. MISS-E: A Method of Modeling of Socio-Economic Systems, Report SPR 52, Futures Research Center, Technical University of Wrocław (1981).
6. Kwaśnicka, H. and Kwaśnicki, W. Agriculture Simulation Model, Report SPR 73, Futures Research Center, Technical University of Wrocław (1982).
7. Lendaris, G. G. Structural modeling—A tutorial guide. *IEEE Trans. on Systems, Man, and Cybernetics* Vol. SMC-10:807–840 (December 1980).
8. Linstone, H. A., et al. The use of structual modeling for technology assessment. *Technological Forecasting & Social Change* 14:291–328 (1979).
9. Lipiński, H. and Tydeman, J. Cross-impact analysis: extended KSIM. *Futures* 112:151–154 (1979).
10. Wakeland, W. QSIM2: A low-budget heuristic approach to modeling and forecasting. *Technological Forecasting & Social Change* 9:213–230 (1976).

Received 7 June 1982; revised 30 March 1983