A FRAMEWORK FOR DISCUSSION OF MODEL CONCEPTUALIZATION+

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ABSTRACT

The process of attaining a useful model embraces the conceptualization, formulation, and testing stages.

This paper argues that effective conceptualization can be achieved through a dynamic hypothesis (that is, a chosen time development of interest and hypotheses about the underlying mechanisms).

The resulting rough, conceptual model should then be improved gradually through a recursive procedure where the model is tested, redesigned and tested again, in as many ways as possible and as long as is feasible.

The paper attempts to structure the hazy topic of model construction by defining a number of terms, and presents lists of dysfunctional tendencies in and guidelines for model construction.

+ An early version of this paper was presented at the Soviet-American Conference on Social Simulation, Sukhumi, Georgia, USSR, October 17 - 24, 1973.

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INTRODUCTION

The need for guidelines for model conceptualization

In spite of the existence of innumerable social system models, there is not much available literature, and probably not much knowledge extant, about the process by which such models are constructed. How is a problem chosen? By what process does one choose the model variables? How does one achieve a useful perspective on the problem area? How does one succeed in capturing in a relatively simple model the essentials of a complex, real-world phenomenon? Models are, nearly without exception, presented in "final" form, as though a thing as The Model exists and as though the process of arriving at a fruitful description of some aspects of reality is straightforward and not worthy of explicit attention. The lack of information about the modeling process, particularly its first stages,[1] is probably due to the "pre-scientific" state of the art of model conceptualization and formulation. The conceptualization phase, in particular, seems to be governed largely by intuition, inspiration, and luck. The difficulties are particularly extreme in the modeling of social problems, because the modeler must represent aspects of the real world that cannot be easily observed and measured, and because social systems are more complex than physical systems.

Due to lack of information to the contrary, the sequences of presentation in published papers describing models are commonly mistaken for the actual steps in the creation of those models. More study and description of the

1. I see the model development process as consisting of three major phases: conceptualization (obtaining a perspective on and mental understanding of the real-world phenomenon); model formulation (representing the acquired understanding in some formal language); and model testing (subjecting the formal model to various tests and criteria of acceptability).

modeling process is likely to eliminate that misconception, as well as other barriers to effective modeling, and also to provide guidelines for model construction to the less-experienced.

To make model conceptualization less of an art, more efficient, and eventually, a subject that can be taught, modelers must consciously analyze the process and how it can be performed effectively. The accumulation of such knowledge presupposes, at the minimum, agreement on the meaning of "conceptualization," and on some defined terms in which to couch the discussion. This paper presents a framework for description and analysis of model conceptualization, which may serve to orient further work in the area. The presentation of a foundation for analysis of conceptualization is justified by the dearth of earlier publications with this goal.[2] The paper also outlines an apparently effective procedure for constructing social models. The suggested procedure is certainly not the only possible approach; further experience and research will have to show whether it is preferable. Finally, some guidelines are advanced with the intent of further aiding the modeler in his conceptualization. The recommended procedure and the guidelines should be viewed as examples of how to proceed in the unexplored area of model conceptualization. Each must obviously be refined to improve the chances of success for the inexperienced modeler.

Descriptive, generic, dynamic models

In the most general terms, a model is constructed in an attempt to increase understanding of the real world, often to facilitate control of the human environment. On a less aggregate level, a multitude of different objec-

2. The author's unpublished doctoral dissertation Conceptualizing Dynamic Models of Social Systems: Lessons From A Study of Social Change (A.P. Sloan School of Management, M.I.T., September 1973) reviews the existing literature on conceptualization.

tives may inspire efforts at model construction: for example, description; design; prediction; optimization; management; training or education; detection; reduction of uncertainty; and aggregation. Any model will satisfy all of these objectives to a certain degree; however, the typical model satisfies a few objectives to a larger extent than others. The utility of a model is determined by how well it satisfies the objectives selected as important by the user. Consequently, the utility of a model cannot be objectively assessed without prior agreement on which objective the model is to serve. Furthermore, without agreement on objectives, it is impossible to decide whether a given modeling approach is having increasingly better results. Which among various available modeling strategies will be optimal depends on the chosen set of model objectives. One conceptualization procedure may well be productive in obtaining one type of model, but not another.

The substance of this paper is most relevant for construction of one particular type of model: the descriptive, generic, dynamic social system model. A descriptive model, representing some real-world phenomenon, is constructed to gain and communicate insight about the operation of that aspect of reality, and to help control it. A generic model draws attention to some structure common to a large class of real-world situations, omitting the special aspects not characteristic of most members of the class. A dynamic model is designed to investigate developments through time. Descriptive, generic, dynamic models of social problems help to explain the typical behaviour modes of a system, not to predict its exact state at some specific point in time. Such models also contribute to the development of better policies, but they are not constructed to perform formal optimization.

THEORETICAL FRAMEWORK

The meaning of conceptualization

Briefly, the conceptualization phase of model construction entails problem definition and creation of the central features of the model addressing the chosen problem. Model conceptualization includes, for example, selection of a system boundary and level of aggregation, choice of a perspective on the simuland,[3] and identification of basic mechanisms and main variables to include in the model.

Figure 1 presents another way of looking at conceptualization. In modeling, distinctions should be made between the real world under study, the modeler's understanding of that part of reality, and the formal representation (that is, the model) of his understanding. Through the process of modeling, the modeler gradually moves from contact with a poorly understood real phenomenon to possession of a formal representation of that situation. The process, usually highly iterative, includes two phases. In the complex, unstructured conceptualization phase, the modeler achieves a "mental model," that is, an opinion about the operation of the real world. Such insight is a prerequisite for formulating any model. The simpler formulation phase entails setting down the mental model as a formal, accessible, written description. Actually, the modeling process passes through numerous recursions into both phases.

Figure 2 contains a third operational description of conceptualization. The list includes all the necessary activities in the construction of descriptive, generic, dynamic models. Conceptualization, a summary term, encompasses the first eight activities in the list. The essence of these activities is

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3. The term "simuland," suggested by John McLeod, denotes the aspect of reality being simulated.

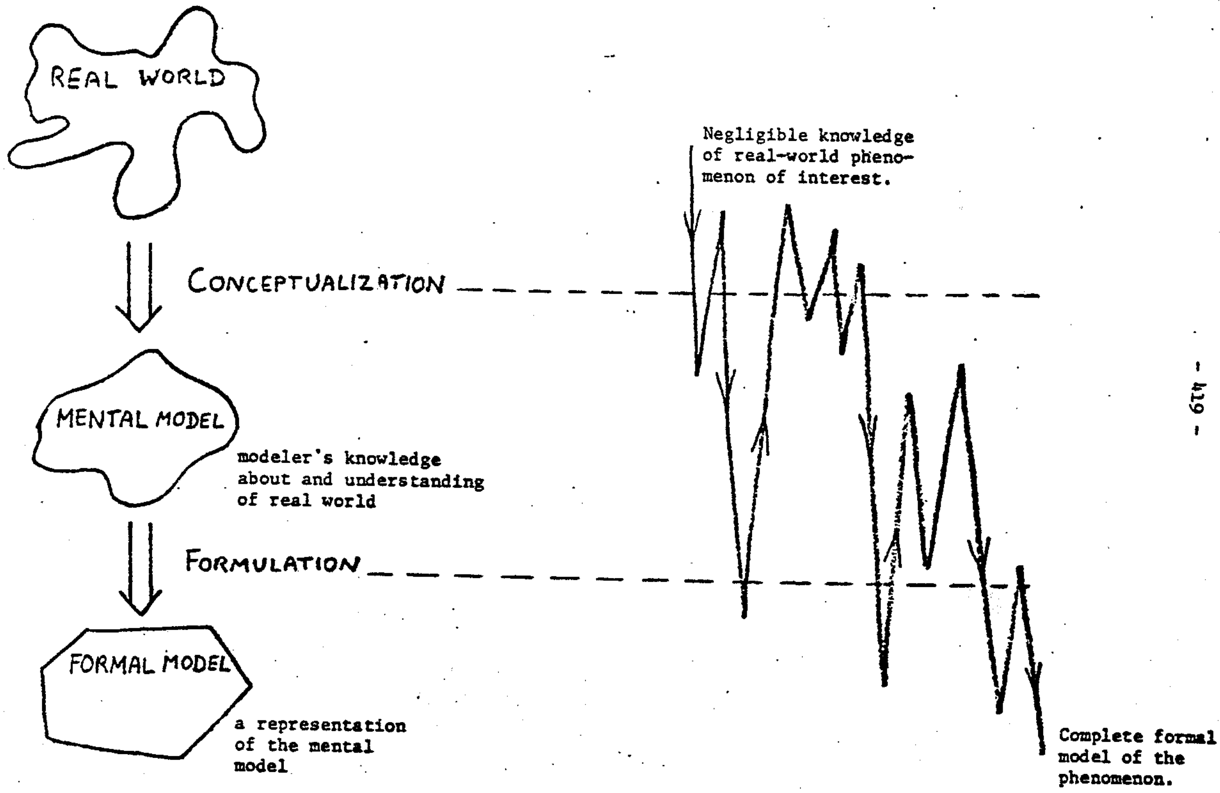

Figure 1: The Modelbuilding Process Consists of Two Major Phases: Conceptualization and Formulation. The Process Is Recursive.

CONCEPTUALIZATION.....
- --Familiarization with the general problem area
- --Definition of the question to be addressed
- --Exploration of real-world behavior and structure relevant to the question
- --Description of the dynamic behavior of interest
- --Development of organizing concepts
- --Definition of system boundary through verbal description of system feedback loops
- --Representation of feedback loops in causal diagram form
- --Identification of system descriptors

FORMULATION...........
- --Postulation of detailed model structure
- --Specification of a set of parameter values

TESTING ....
- --Testing of model assumptions
- --Simulation to test model behaviour and sensitivity to perturbations
- --Experimentation with different policies

Figure 2: The Activities Involved in Construction of Descriptive, Generic, Dynamic Models of Social Systems.

illustrated by the following example, which describes, in an idealized manner, the erection of the foundation for the World3 model of growth in a finite world.[4]

Familiarization with the general problem of material growth in a physically finite world was acquired through daily experience, news reports, and the literature. After much thought, the question to be addressed was defined: Will human material activity adjust smoothly to the global carrying capacity or go through a period of overshoot and collapse? Further exploration led the modelers to emphasize the erodability of the carrying capacity (for instance, through soil erosion due to intensive agriculture, or destruction of the self-cleansing capacity of the ecosystem due to excessive pollution). Such reduction in the earth's ability to sustain its population can result from over-utilization due to man's tendency to delay the response while waiting for more knowledge about the position of physical constraints.

The possibility of collapse because of the excessive load placed on the physical environment drew attention to the dynamic behaviour sketched in Figure 3a. The behaviour mode of overshoot and decline appeared to be a likely consequence of current trends. Since overshoot was judged undesirable, it seemed worthwhile to investigate the causes of that behaviour and try to determine how a change in growth policies might achieve the gradual accomodation depicted in Figure 3b. Figures 3a and 3b together represent the reference mode of the global modeling study that culminated in the World3 model.

After developing organizing concepts -- "human material activity," "car-

4. Further description of the model and its conclusions can be found in D.H. Meadows, D.L. Meadows, J. Randers, and W.W. Behrens The Limits to Growth (New York: Universe Books, 1972), and in D.L. Meadows, W.W. Behrens, D.H. Meadows, R. Naill, J. Randers, and E.K.O. Zahn The Dynamics of Growth in a Finite World (Cambridge, Mass.: Wright-Allen Press, 1974).

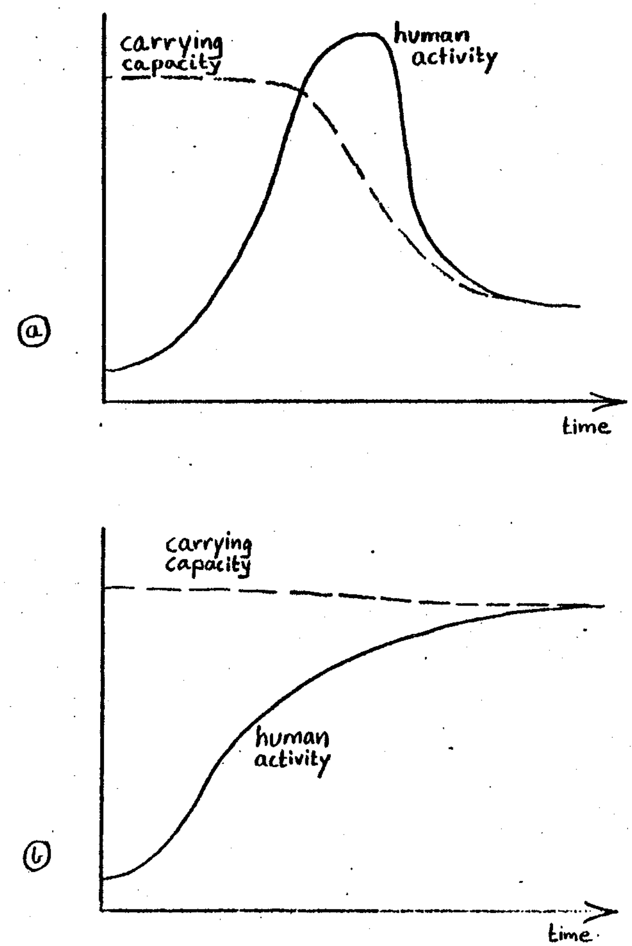

Figure 3: The Reference Mode for the World3 Model of Physical Growth in a Finite World.

rying capacity," and "delayed response" to the proximity of constraints -- the modelers were able to discuss more easily the question addressed. The concepts also facilitated verbal description of the following group of processes judged responsible for the reference mode:

1. The level of human activity increases when there is room for expansion, i.e. unutilized carrying capacity.
2. A sufficiently high level of human activity erodes the carrying capacity of the global environment.
3. There will be no response in the form of deliberate reduction of an excessive load until after a delay, spent in data gathering and institutional change.
4. Exceeding the carrying capacity forces an involuntary downward pressure on human activity -- for example, through starvation.

The system defined by these interactions can be represented by the causal diagram in Figure 4. The arrows and signs indicate the direction and polarity

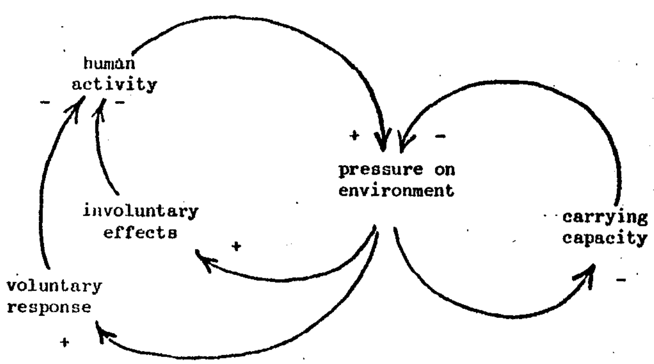

Figure 4: The Basic Mechanisms of the World3 Model in Causal Diagram Form

of the depicted causal influence. The causal diagram depicts the "basic mechanisms" of the World3 model of growth toward finite limits; that is, the smallest set of feedback processes considered sufficient to generate the reference mode in Figure 3.

Taken together, the reference mode and the basic mechanisms constitute the "dynamic hypothesis" of the study. An early task in the modeling process is to test the dynamic hypothesis, that is, to check whether the basic mechanisms actually can generate the reference mode.

Finally, a set of system descriptors was identified. This set of levels (state variables), considered sufficient to describe the system under study, consisted of "human activity," "carrying capacity," and "voluntary response to environmental pressure" (a measure of the willingness to control further expansion of activity). The conceptualization process, summarized here rather unrealistically as a smooth linear progression, finally did yield the mental model of the world as a finite system to which man must ultimately accomodate, and the dynamic hypothesis that accomodation may well occur through an overshoot caused by delays in perceiving imminent constraints.

Formulation and testing

In the same way that conceptualization -- reaching a dynamic hypothesis about the relation between a certain behaviour and a given causal structure -- is an iterative process, the ensuing formulation of the formal computer model proceeds in a recursive manner. Starting from a simple, initial conceptual model, encompassing little more than an aggregate description of the basic mechanisms, one gradually moves toward a more complete description. The conceptual model should, however, be sufficiently detailed to allow testing of the dynamic hypothesis.

The formal computer model was constructed upon completion of the conceptualization phase. A complete representation of the postulated model structure as it was included in the conceptual model, depicting the detailed choice of variables and their interrelations, is displayed in the DYNAMO flow diagram in Figure 5.[5] The flow diagram contains more information than the causal diagram in Figure 4. For instance, Figure 5 reveals the additional structural assumption that recovery of eroded carrying capacity is possible. Estimation of a set of parameter values for the structure entailed making a decision as to the strength of the various model relations and the length of the associated time lags. The parameter values chosen are specified in the DYNAMO equations in Figure 6, which provides a complete formal description of both model structure and parameters for the conceptual model.

Figure 7 shows two simulation runs generated by the conceptual model. Run A verifies the dynamic hypothesis. It shows that an overshoot in human activity actually can result from the structure depicted in Figure 5. Growth in human activity continues in this run until involuntary physical pressure forces a halt, at a time when one is already above the sustainable level. Run B shows that the possibility of removing overshoot through anticipatory, voluntary attempts at halting growth before the sustainable limit is reached.

After successfully running the conceptual model, the modelers began a long process of discovering and correcting errors and weaknesses, and extending and elaborating the original model to obtain increasingly "better" models. Ultimately, they arrived at a model which appeared sufficiently credible to warrant experimentation to devise improved policies for managing the world system. Approximately twenty person-years of gradual extension and elaboration of the conceptual model led to the version of the model (called World3 and

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5. More information about the DYNAMO flow charting conventions and computer language is available in J.W. Forrester Industrial Dynamics, (Cambridge, Mass.: MIT Press, 1961) and Alexander Pugh III DYNAMO User's Manual, (Cambridge, Mass.: MIT Press, 1973).

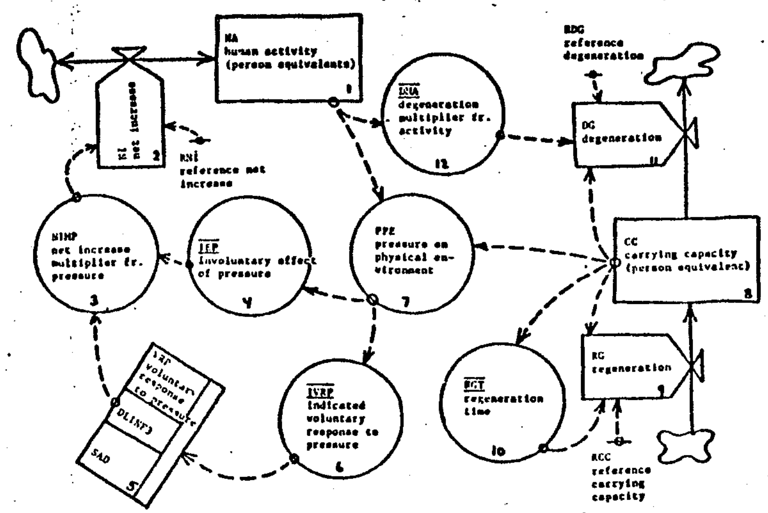

Figure 5: DYNAMO Flow Diagram for the conceptual model underlying the World3 Model.

Levels, or physical quantities that can be measured directly, are indicated by rectangles, rates that influence those levels by valves, and auxiliary variables that influence the rate equations by circles. Time delays are indicated by sections within rectangles. Physical flows of people, goods, money, etc. are shown by solid arrows and non-physical information flows by broken arrows. Clouds represent sources or sinks that are not important to the model behaviour.

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         *           THREE LEVEL WORLD MODEL
           NOTE
           NOTE        HUMAN ACTIVITY SECTOR
1          L      HA.K=HA.J+DT*NI.JK
           N      HA=HAI
           C      HAI=1.6E9
2          R      NI.KL=HA.K*RNI*NIMP.K
           C      RNI=.0055
3          A      NIMP.K=(VRP.K+IEP.K)
4          A      IEP.K=TABLE(IEPT,PPE.K,0,3,.5)
           T      IEPT=1.5/1.5/1.0/0.0/-1.0/-3.0/-10.0
5          A      VRP.K=DLINF3(IVRP.K,SAD)
           C      SAD=30
6          A      IVRP.K=TABLE(IVRPT,PPE.K,0,3,.5)
           T      IVRPT=1.0/1.0/0.0/-.5/-1.0/-1.0/-1.0
7          A      PPE.K=HA.K/CC.K
           NOTE
           NOTE         CARRYING CAPACITY SECTOR
8          L      CC.K=CC.J+DT*(RG.JK-DG.JK)
           N      CC=CCI
           C      CCI=7.5E9
9          R      RG.KL=((RCC-CC.K)/RGT.K)
           C      RCC=1.0E10
10         A      RGT.K=TABLE(RGTT,(CC.K/RCC),0,3,.5)
           T      RGTT=400/100/50/40/30/30/30
11         R      DG.KL=CC.K*RDG*DMA.K
           C      RDG=.004
12         A      DMA.K=TABLE(DMAT,(HA.K/HAI),0,10,1)
           T      DMAT=1/1/2/3/4/6/10/18/30/50/80
           NOTE
           NOTE          CONTROL STATEMENTS
           SPEC    DT=.5/LENGTH=0/PLTPER=10
           PLOT    HA=H(0,16E9)/CC=C(0,7.5E9)
           N       TIME=1900
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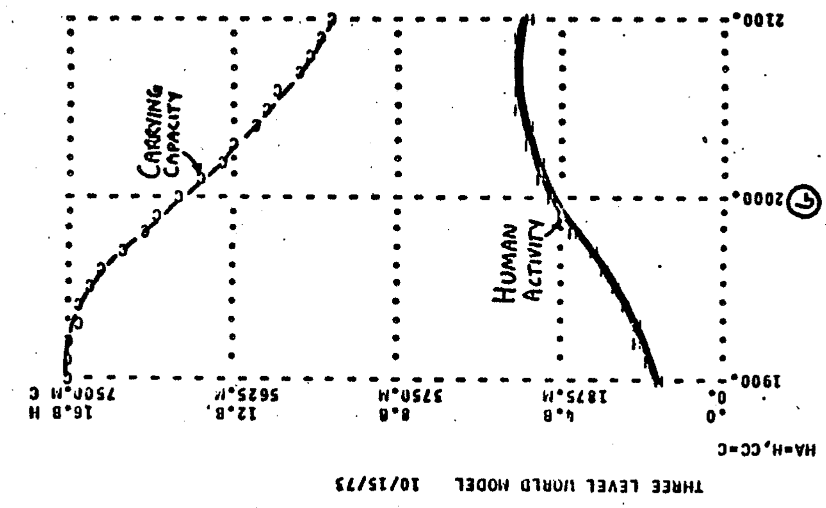
Figure 6: DYNAMO Equations for the conceptual model underlying the World3 model.
(The equation numbers to the left correspond to the numbers on the flow diagram elements.)



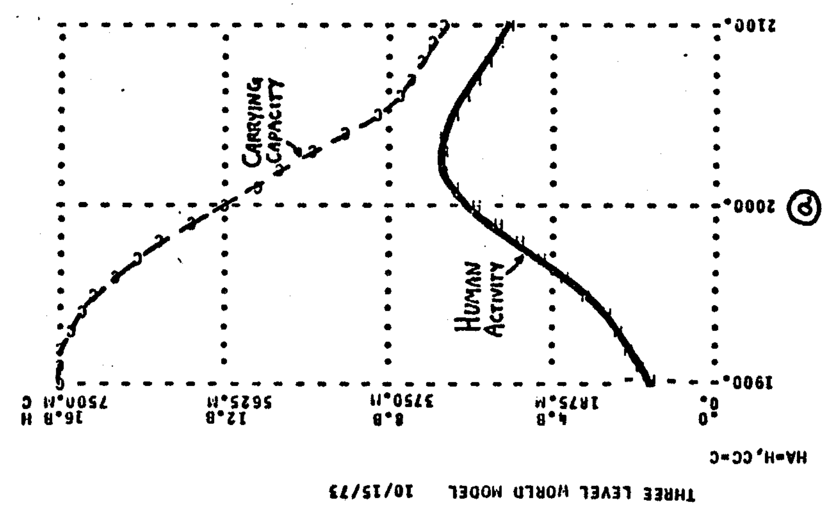


Figure 7: Runs of the conceptual model underlying the World3 model
a) Erosion of carrying capacity.
b) Material equilibrium through change in social policies.
(To obtain run b), the following alternative parameter values were used: SAD=10, IVRPT=1/0/-1/-2/-3/-3/-3.)

shown in Figure 8) that was published. Figure 9, showing two World3 runs, shows how the reference mode is still intact even though World3 has twenty-one levels versus three in the conceptual model. The increased detail simply makes the concepts sharper and the structure richer in "realistic" relations. The basic structure of the expanded World3 model is still similar to the conceptual model in Figure 5, although the World3 structure now appears in a less aggregate, more "realistic" (and confusing) form.

A CASE STUDY

An actual modeling process

The above discussion has illustrated the full range of activities involved in descriptive, generic, dynamic modeling. Typically, the activities are performed in other sequences. Often, several activities are performed simultaneously. One major goal of a theory of effective conceptualization would be the identification of the most productive sequence of activities and the proper emphasis to be placed on different activities.

The following description of one actual modeling project is intended to indicate the fumbling character of the process, to illustrate the difficulties encountered, and to make the ensuing abstract discussion of modeling more meaningful. The modeling project focused on the general question of how societal beliefs and attitudes change in response to the deliberate action of a social movement striving to spread new ideas. The project goal was to construct a system dynamics model of the diffusion process with the intent of identifying more effective policies for movements seeking social change.[6]

6. A detailed description of the effort to model diffusion appears in <u>Conceptualizing Models of Social Systems: Lessons from a Study of Social Change</u> (op.cit.).

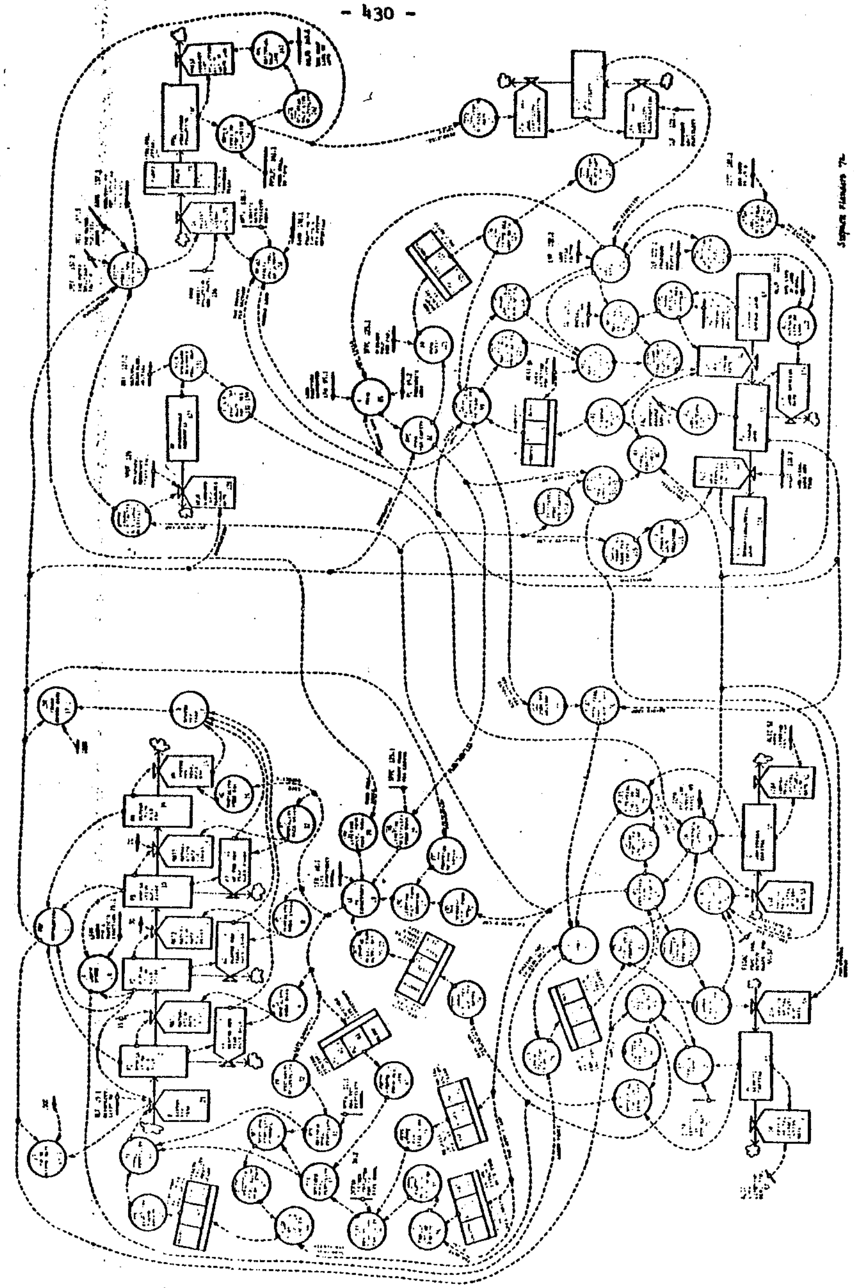


Figure 8: DYNAMO Flow Diagram for the World3 model.

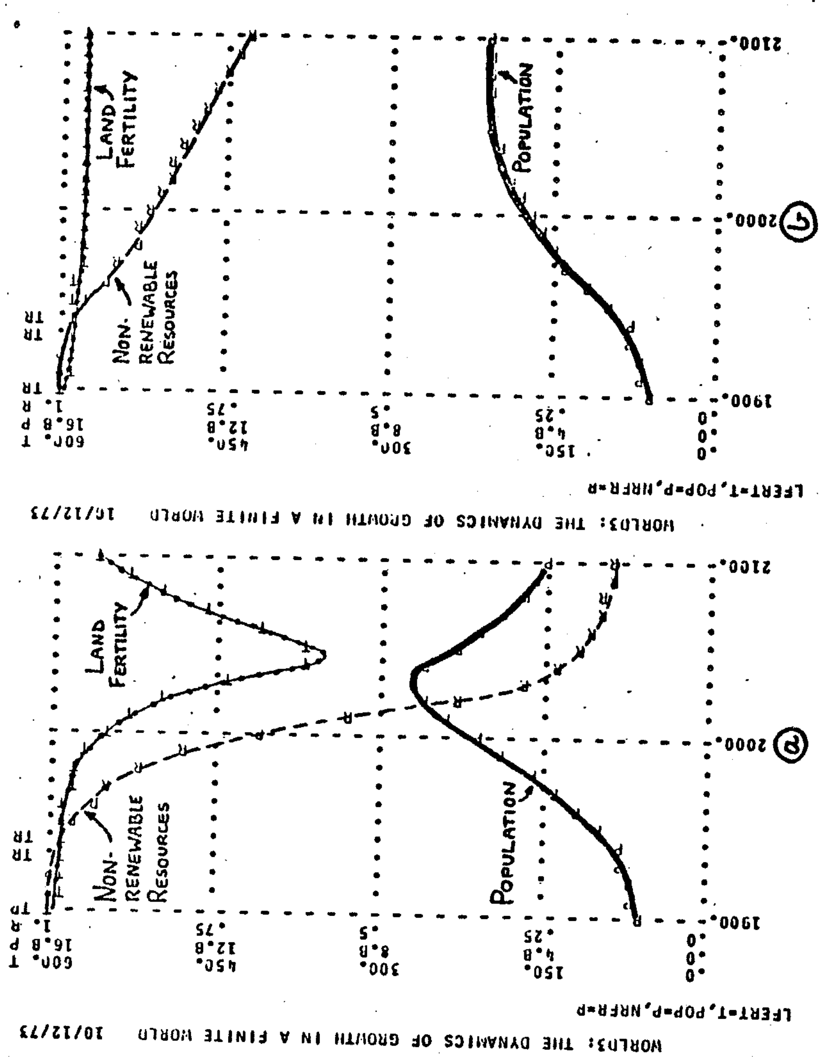


Figure 9: Runs of the World3 model.
a) Erosion of non-renewable resources and soil fertility.
b) Material equilibrium through change in social policies.
(The runs are procedurally equivalent to Runs VII-6A and -28 in Dynamics of Growth in a Finite World (op.cit.), but different variables are plotted.)

The progress of the first nine months of the effort is depicted in Figure 10. The figure illustrates the sequence of activities and the shift of emphasis throughout the period. The major characteristics of the effort was its iterative nature, represented by several attempts at obtaining an acceptable model. The project progressed through several rounds of conceptualization, formulation, and testing. Each run through the list of activities was eventually terminated when critical evaluation of the current approach found it wanting in some respect, forcing a return to further conceptualization. Eleven different tentative models were constructed in this iterative fashion, then discarded shortly thereafter. Some were abandoned at the causal diagram stage, others only upon completion of a running model. Only the twelfth approach passed the various tests of relevance and completeness, and was judged to have potential for significant elucidation of the issue of social change. In other words, the twelfth attempt (labelled "NEW IDEA" in Figure 10) yielded a promising conceptual model. This model was not considered a final product, but it did embrace the basic characteristics of a "good" end result.

First of all, the conceptual model contained a seemingly productive set of basic mechanisms. Second, it appeared capable of addressing the issue at a desirable level of complexity. Third, the model structure exhibited a reasonable division between variables describing the movement itself (the "group"), the target for its activity (the "society"), and characteristics of the point of view promoted by the movement (the "idea").

Through consecutive rounds of improvement (over a period of time subsequent to that in Figure 10) the conceptual model was elaborated and extended into an increasingly useful model. Improvement also required conceptualization activities, but hardly to the extent needed to develop a satisfactory conceptual model.

Figures 11 and 12 offer a perspective on the gradual development of the

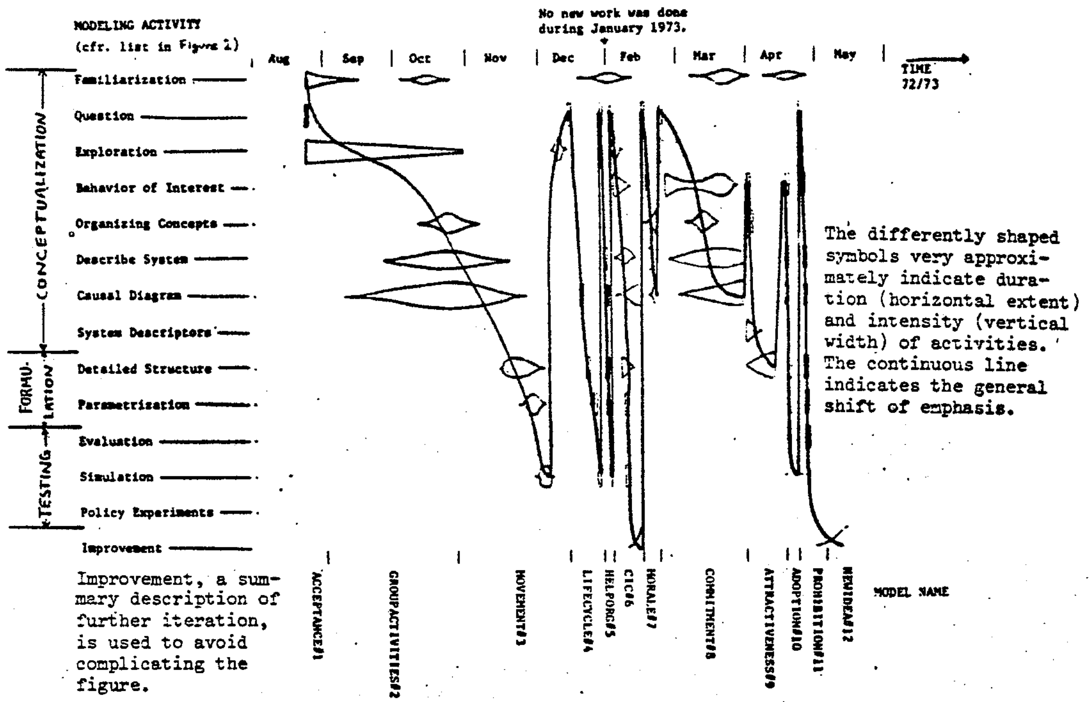


Figure 10: The Sequence of Activities During the Effort to Model Social Change.

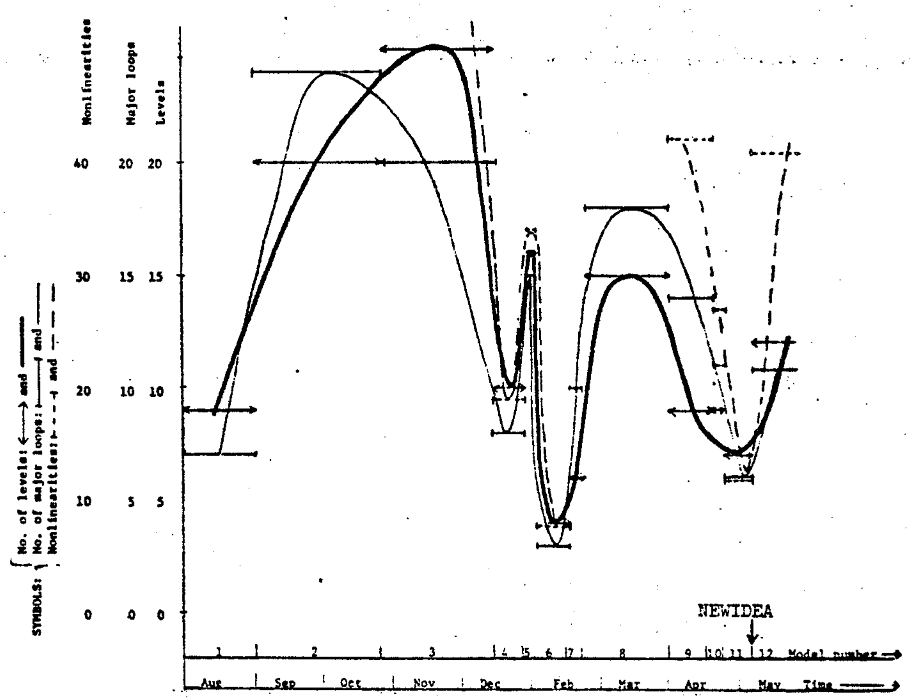


Figure 11: Trends in Model Complexity.

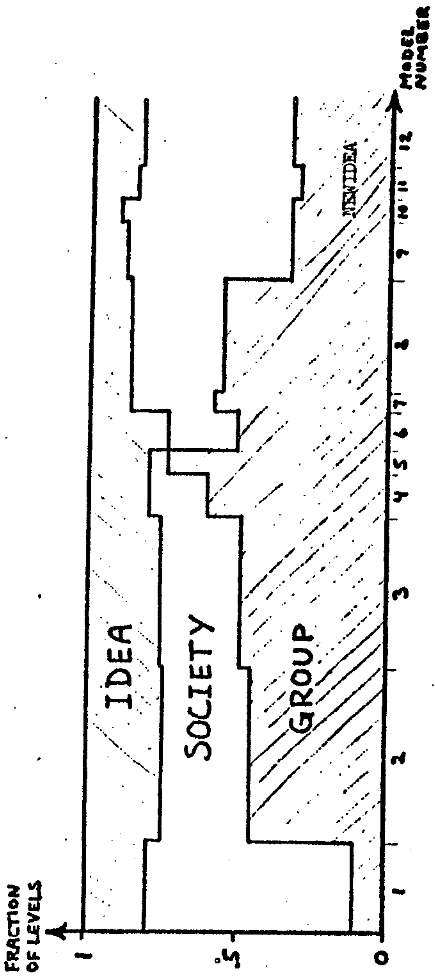


Figure 12: Trends in Relative Model Emphasis.

characteristics of the models preceding and leading up to "NEW IDEA." Figure 11 shows the trend in several measures of model complexity -- the number of levels (indicating the order of the system), number of major feedback loops, and the number of non-linear relations in the model. The time trends in number of levels, non-linearities, and major loops are similar, indicating an interesting constant proportionality among the entities (approximately one loop and two non-linearities per level). Starting from a simple model, the study passed through a phase of extreme complexity, then returned to increasingly simple models. Another period of complex models gave way to several simple models. "NEW IDEA" is located in this process where a third start was made toward more complex description of the simuland. The graph might be interpreted as describing a process approaching via damped oscillations a goal of complexity equivalent to about ten levels.

Given the large variation in model complexity and approaches attempted, Figure 12 shows an astonishing continuity in the relative emphasis put on the three elements of the simuland. The ultimate distribution of levels (33, 17, and 50 per cent, describing group, idea, and society, respectively) is the end point of an evolution process in which an early emphasis on societal descriptors gave way to a period of focusing on internal group processes, before more balanced model again prevailed. At the peak (Model Number 5), the study centered almost solely on group processes; less than 10 per cent of the levels were related to society. The dynamic description of the idea was always constrained to between 10 and 25 per cent of the levels.

The construction of a model is not a one-shot process, with one single objective to be achieved or not. Theory construction is a continuing iterative process toward an increasingly useful model, thereby satisfying the modeler's objectives to an ever-increasing extent. A theory of effective model creation should improve the consistency of this iterative process.

S U G G E S T E D P R O C E D U R E

G e n e r a l i z e d t e s t i n g

Models become "better" through repetitive testing and correction of weaknesses. But what criterion should be used to identify weaknesses? In the physical sciences, models have been successfully improved by comparing model-based point predictions with quantitative observations. Physical models are evaluated solely on the basis of how well they predict detailed events at specified points of time. This procedure is not optimal for improving relatively simple models of complex social systems. Simple models of complex systems exhibit a significant stochastic element, so there is little guidance to be obtained from comparison of detailed model prediction and specific real-world observations. In upgrading social system models, it may be better to employ a much broader set of model tests. In an alternative generalized testing process, all aspects of the model (not only model predictions) are tested, using all available knowledge (not only quantitative data).

Generalized testing appears to be the obvious approach if the modeler refrains from viewing statistical, quantitative tests as the only guide to upgrading a model. Tests need not be restricted to only one characteristic of the model: for instance, its ability to predict pinpoint events for which quantitative data are available. Dynamic models have several other attributes that can be tested including:

- the capacity of the model to generate behaviour modes corresponding to those of the simuland, both under normal and extreme conditions;
- the plausibility of the individual structural assumptions (the variables and their assumed interrelations) chosen to represent the simuland;
- the plausibility of the numerical values chosen for the model parameters; and

- the completeness with which the model includes the mechanisms thought to generate the problem addressed.

The first criterion comes into play only if the other criteria are already satisfied. An infinite set of models is capable of reproducing any given collection of behaviour modes. Therefore, a descriptive, dynamic model should not be judged useful unless the individual underlying assumptions exhibit clear relations to the analogous real-world mechanisms, even if the model is capable of reproducing observed behaviour.

In judging how well a model meets the listed criteria, the modeler need not restrict himself to the small fraction of knowledge available in a numerical form fit for statistical analysis. Most human knowledge takes a descriptive, non-quantitative form, and is contained in the experience of those familiar with the system, in documentation of current conditions, in descriptions of historical performance, and in artifacts of the system. A model should draw upon all sources of available knowledge.

The process of judging all aspects of a model in the light of available knowledge about the simuland is termed generalized testing, to indicate its breadth relative to the narrower process of testing a model's predictive ability in terms of statistical tests.

Generalized testing of a tentative model is a rigorous testing procedure. Models can be subjected to generalized testing at all stages of their construction, and revisions undertaken whenever the models fail to satisfy some criterion. Other evaluative criteria can also be introduced:

- The model must be transparent (understandable), and must generate endogenously the dynamic behaviour of interest.
- The individual assumptions must be compatible with established knowledge, and form a consistent and plausible whole.
- The variables and parameters must have independent real-world parallels.

-- The model must have a clear focus and a balnaced emphasis on the relevant elements.

Most tentative models do not satisfy these criteria, and the selective process is more stringent if models that seem inelegant (for example by using too many variables to describe simple phenomena) are also rejected.

Regardless of modeling technique, the use of descriptive knowledge and intuition is indispensable in the initial conceptualization of a model. Subsequent upgrading may be divided into two stages: a first stage, where the modeler judges the model on the basis of his knowledge of the real-world system; and a second stage, where the model is subjected to more formal tests. When dealing with descriptive models, it seems unreasonable to proceed to the second stage if the model does not pass the first "common sense" tests. Generalized testing embraces both methods of model evaluation.

A model structure that satisfies the criteria presented here is not necessarily an incontestable description of reality; nor is it The Only Model. On the other hand, it is certainly not a random accumulation of assumptions, since most conceivable structures would be eliminated by unacceptable performance relative to one or more of the criteria. Having survived generalized testing, a model acquire a certain stature and is ready for as many additional, preferably rigorous tests as time and interest will sustain.

A recommended sequence of modeling activities

Generalized testing appears to be a strong, practical procedure which provides substantial guidance in the construction of descriptive, generic, dynamic models of social systems. It can be employed at all stages of modeling and also during the early conceptualization. However, to create a new model, it is not sufficient to test and criticize an existing structure. The modeler must be capable of building new structures in the first place.

A suggested approach to the problem of model construction is summarized graphically in Figure 13. The figure implies that some characteristics of the modeling process are likely to remain unchanged regardless of how well the modeler masters his art. These characteristics include the iterative nature of testing and correction of flaws (represented by the narrow oscillating curve), and the partly parallel performance of all modeling activities. No amount of suggestions and prior lessons will transform modeling into a sequential execution of a set of activities requiring no repetition. The self-corrective mechanism of recurring invention and testing is in fact desirable during problem definition, testing of the conceptual model, and model improvement, as long as the number of iterations remains reasonable. The recommended approach is merely designed to reduce the number of <u>futile</u> iterations by imposing some structure (represented by the broad band in Figure 13) on the process.

The modeling process can be viewed as split into an <u>initial modeling stage</u> and an <u>improvement stage</u>. The goal of the initial modeling stage should be to arrive at a rough conceptual model capable of addressing a relevant problem. The initial modeling stage should embrace two processes: problem definition (eventually a description of the dynamic behaviour to be studied) and testing of the dynamic hypothesis (a preliminary check to see that the mechanisms included in the conceptual model actually reproduce the dynamic behaviour of interest). The goal of the improvement stage should be to extend and elaborate upon the conceptual model until it is sufficiently versatile and detailed to serve the model's intended purpose.

The modeler should begin by actually drawing the time pattern(s) of the major variables of interest. That is, he must select a process (observed or hypothetical), taking place through time, to represent the problem or phenomenon of interest. The chosen process should then be described in terms of the time-varying behaviour of certain key variables, and sketched on a graph.

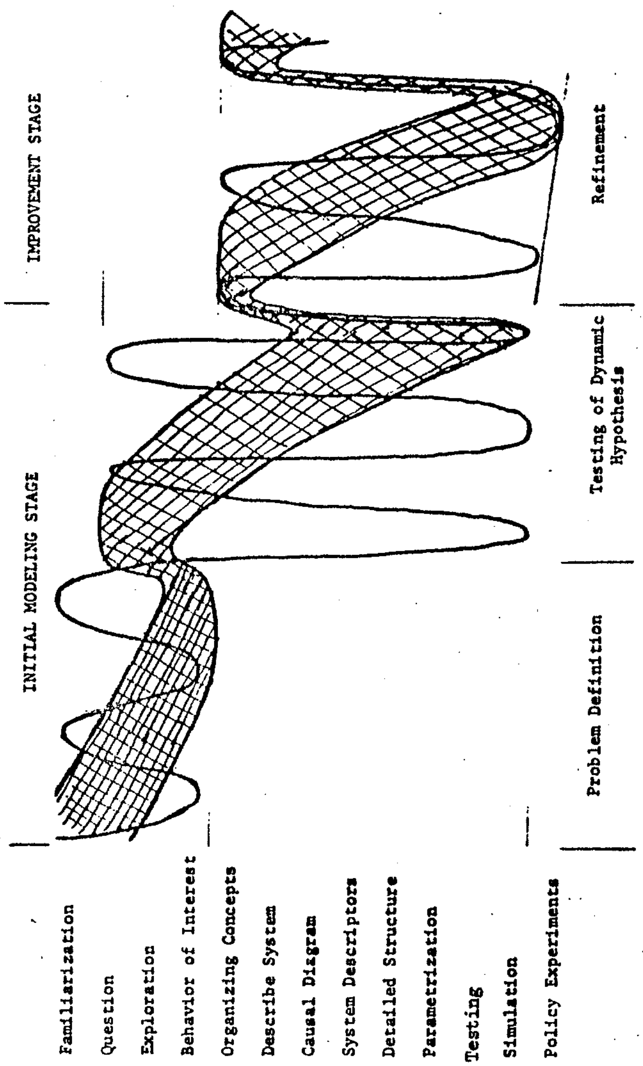


Figure 13: The Recommended Modeling Procedure

Only the most general features of the behaviour should be recorded. The depicted dynamic behaviour of interest, termed the reference mode, serves as an approximate picture of the expected output of the conceptual model. The reference mode is not necessarily restricted to one time pattern; several characteristic behaviours may be required to properly define the problem. For models of past phenomena, the reference mode should essentially consist of the historically observed behaviour which the conceptual model should reproduce. For models of future situations, the reference mode should be the set of alternative development patterns which the conceptual model should be able to generate through variations in model parameters. The reference mode helps the modeler to define the problem with greater clarity; it determines the time horizon of the study; and it also hints at what causal mechanisms to include in the conceptual model.

Once a reference mode has been identified, the stage of problem definition is complete. In final form, the problem should be described in terms of a few selected time patterns (for example, representing actual and desired behaviour). The ultimate definition of the problem decisively influences the result of the whole modeling effort. Identification of a meaningful soluble problem at the outset will preclude much unnecessary iteration. Only very tentative exploratory causal structures should be sketched out during this stage. The problem definition process should be strongly iterative, entailing simultaneously the four activities of familiarization, questioning, exploration, and identification of dynamic behaviour.

Having specified the dynamic behaviour of interest, and thereby the problem for study, the modeler should then identify the collection of fundamental, real-world mechanisms assumed sufficient to reproduce the reference mode. The smallest set of feedback processes considered sufficient to generate the reference mode will be referred to as the basic mechanisms. The first step should be the verbal description of the basic mechanisms. As many traces as possible of less important details should be excluded until only the basic structure remains. Forcing himself to express his assumptions in writing is an excellent way for the modeler to get rid of non-essential concepts. A quick sketch of the basic mechanisms in causal diagram form may focus the modeler's thoughts and help him to visualize the system boundary. The sketch should be very simple (few loops), describing only fundamental mechanisms.

The dynamic behaviour of interest -- the reference mode -- and the related basic structure -- the basic mechanisms -- determine in a precise way the aspect of reality to be studied. The reference mode forces the modeler to study a specific dynamic phenomenon rather than "describing a system." The basic mechanisms force the modeler to address a meaningful whole at all stages of model refinement. Subsequent models simply describe in more detail the fundamental processes already present in the conceptual model.

The belief that the basic mechanisms can actually reproduce the reference mode is still only an assumption until simulation of a model embracing the mechanisms proves this dynamic hypothesis to be correct. The modeler should therefore build the conceptual model, consisting of the basic mechanisms, and simulate (run) it to test the dynamic hypothesis -- that is to check whether the basic mechanisms can actually generate the reference mode.

The first step in formulating the conceptual, rough model should be identification of the system levels. The levels describe a set of independent variables, together sufficient to describe the state of the system. The modeler begins by compiling elements sufficient to describe the state of the closed system being modeled. The list should be complete. Redundancies are eliminated when the modeler selects the levels from among the list of elements. To extract a set of levels, the modeler should continually eliminate the remaining list entries that are not independent of the elements already chosen as levels.

After selecting the levels and the necessary associated rates, which govern change in the levels, the modeler should add the causal influences on the rates. These causal influences capture the basic mechanisms which the model is supposed to include. The modeler should be able to construct a DYNAMO flow diagram at this point.

Next, the modeler should choose numerical values for table functions and time constants. Without belabouring the activity, he should then subject the completed structure to a first set of tests with respect to consistency, completeness, and reasonableness in its individual assumptions. If found satisfactory, the model should be run to determine whether it actually reproduces the major characteristics of the reference mode. If the model fails in either of these two preliminary tests, its flaws must be corrected in a new iteration. A new iteration may involve retracing all steps, beginning with an altered problem definition. When the model passes both tests and addresses a problem of interest, the resultant model is worthy of entry into the improvement stage.

The improvement stage consists of a never-ending series of extensions and elaborations to increase model richness or realism through changes in system boundary, level of aggregation, or detailed formulation. In most cases, improvement means making the model more complex. Since all models should be transparent, care must be taken to include new relationships only when they are necessary for adding a desired behaviour mode, testing the effect of a policy, or attaining credibility with non-modeler users. The enrichment process must not be pursued to the point where the modeler can no longer grasp the connection between model assumptions and model output. During the improvement stage, the modeler may encounter powerful organizing concepts that make possible the reformulation of the whole study in a simpler, more elegant form. Such concepts, a valuable by-product of modeling, should be actively sought at all stages of the modeling process.

The reference mode acts as a catalyst in the transition from general speculation about some part of reality to the routine improvement of a given model structure. This metamorphosis, manifested in the achievement of a conceptual model, is the major creative step in modeling. Once the conceptual model is attained, the value of the reference mode in guiding progress diminishes. The models obtained later, by improvement, will show a richer variety of behaviours than the original reference mode.

Finally after extensive iteration in the improvement stage, leading to a credible model structure and parametrization, the modeler may perform the policy experiments upon which his conclusion will rest. Any conclusions should always be presented along with the model premises on which they are based. The premises may be organized in the more easily understood causal fiagram format.

T Y P I C A L   D I F F I C U L T I E S

C o m m o n   m i s t a k e s   i n   m o d e l i n g

The modeling procedure outlined here may seem trivial to the novice. However, the value of an explicit theory of model construction may become more obvious if he will consider the following list of common mistakes which most modelers make. A good theory should ameliorate these dysfunctional tendencies.

- Tendency to ramble due to lack of an explicit goal

The first task of any modeling study is to define the goal of the effort. Without no very clear objective it is impossible to decide what to include in a model, what aspect of reality to focus on, and when the result is "good enough."

- Tendency to make excessively complex models to avoid inadvertent omission of important elements

The simplest and safest response to uncertainty about whether a variable is important, is to include it in the model. The modeler thereby evades challenging his own ignorance in an attempt to select only the few important factors. He also avoids the accusation of omission.

- Tendency to exclude too much detail subsequent to failures with overly complex models

In a field of inquiry devoid of guidelines, the modeler can learn only through the negative feedback of experience. In response to failures with excessive complexity, the modeler makes simpler models. Lacking knowledge about what constitutes reasonable simplicity, he may well overreact and thereby slow down his progress toward the proper amount of detail.

- Tendency to contract the scope of the model to permit a complete respectable analysis

If the modeler pays attention to only narrowly defined system boundary, he can include all the elements of the system commonly viewed as relevant, without running into excessive complexity. No difficult choices among variables and relations need be faced, and the study attains an air of impregnable completeness and respectability.

- Tendency to stick to earlier formulations to justify the effort put into their development

It is phychologically difficult for the modeler to abandon a line of approach in which he has expended great efforts, particularly if the approach originally generated promising results. No doubt, a certain persistence is valuable in research to insure that one does not prematurely discard an approach, but there is a danger that commitment built up through the initial conceptualization struggle will keep the modeler from changing his approach when necessary.

- Tendency to overemphasize causal diagramming, since causal diagrams constitute a tangible result without the finality of a completed model

Until something appears on paper, the modeler may feel that a study has been unproductive. This perception is unfortunately persistent, although the initial and largely unwritten familiarization, exploration, and problem definition largely determine the outcome of the project. But while eager to see concrete results, the modeler may have many reasons for wanting to postpone completion of a model. He may hesitate to go through time-consuming computer programming for a model that is still not fully satisfactory. A completed model tends to become "sacred" and unchangable in light of the commitment and the impressive orderliness of a closed consistent perspective on reality. A completed model is also a conspicuous target for criticism. A causal diagram, on the other hand, represents a convenient compromise. The diagram is visible proof of effort; it can be produced without much toil; and it is still clearly unfinished and therefore not so susceptible to criticism.

- Tendency to become stalemated in unending formulation problems, actually brought about by a lack of understanding of the simuland

An accurate representation cannot be obtained from an inadequately understood real-world system. Generic modeling, for example, requires thorough knowledge of the class of simulands studied; otherwise, the modeler will not be able to extract the few, powerful assumptions constituting a useful model. However, when encountering modeling problems, the modeler is easily trapped into believing that the obstacle is the limited capability of the modeling tools to represent reality. Unending, futile attempts at formulating some part of a model are symptomatic of a lack of knowledge of the real system being modeled; the time could be more usefully spent on obtaining a better understanding of the simuland. In extreme cases, apparent formulation problems may induce such frustration and disgust as to force the modeler to discontinue the study. Knowledge constraints become more apparent when using powerful, versatile techniques.

To avoid pitfalls

The ten guidelines listed below[7] can help to counteract the common tendencies toward error. They can also often impose a more explicit consideration of his activities and more effective working habits on the modeler. Along with the overall strategy suggested in the chapter called "suggested procedure," these guidelines form a body of knowledge to instruct the inexperienced model builder.

Guideline 1:	Explicit description of the dynamic behaviour of interest -- the reference mode -- and assumptions about its cause -- the assumed basic mechanisms -- are necessary prerequisites for successful model building.
Guideline 1a:	A reference mode will not lead to a worthwhile model unless accompanied by assumptions about underlying basic mechanisms.
Guideline 1b:	A set of basic mechanisms will not lead to a worthwhile model without the focus provided by a reference mode.
Guideline 2:	The modeler should consciously look for organizing concepts that are powerful descriptors of the basic mechanisms underlying the reference mode.
Guideline 2a:	Organizing concepts may help to guide modeling and the description of models, but they will not automatically lead to a successful model.
Guideline 3:	A dynamic hypothesis is obtained through exploratory combination of historical (or hypothetical) simuland behaviour and simple structures with known behaviour. Ideas for a productive perspective on reality can be obtained from familiar organizing concepts and existing models.

7. The guidelines are discussed in more detail in <u>Conceptualizing Dynamic Models of Social Systems: Lessons from a Study of Social Change</u>, op.cit.

Guideline 4: The system boundary must be wide enough to encompass feedback loops capable of endogenously generating non-trivial dynamic behaviour over the time period studied.

Guideline 5: The purpose of the initial conceptual model is not to predict, but to test the dynamic hypothesis.

Guideline 6: The conceptual model should only contain the basic mechanisms needed to generate the reference mode; additional complexity should then be gradually incorporated until a sufficiently realistic and versatile model is obtained.

Guideline 7: The model should be kept transparent, even subsequent to the initial modeling stage.

Guideline 7a: A relationship should only be included in a model if necessary to generate a desired behaviour mode, to test effects of a policy, or to achieve sufficient realism to gain credibility.

Guideline 7b: Each model link should represent a stable, meaningful, real-world relationship in which the modeler has confidence.

Guideline 8: Reduce the amount of detail (depth), rather than scope (breadth), if model complexity must be reduced.

Guideline 9: Spend most time on what matters most: a balanced model structure. An elegant, concise formulation and a reasonable parametrization can be obtained later.

Guideline 10: Causal diagrams should be used only for exploration in the initial modeling stage and for communication of the "final" model; the modeling proper should be performed by choosing and linking levels.

UNANSWERED QUESTIONS

The discussion of conceptualization of social models raise innumerable questions. In many cases, answers will have to await the availability of more information about the chronologies of actual modeling efforts. One major task should therefore be to accumulate additional, frank reports on the modeling process, perhaps in the format suggested by the chapter "suggested procedure."

The objective would be, primarily, to gather more knowledge about procedures that are used consciously or unconsciously.

Since very little is known about model conceptualization, the list of specific questions begging answers would be very long. A selection of these questions is provided here:

-- Does the definition of "conceptualization" employed here help to focus attention on the most decisive phase of modeling?

-- Is the strong orientation toward problems, as opposed to study of a system, productive? (Or, perhaps, does focusing on problems help the ordinary modeler limit his attention to a job of manageable proportions, while the expert can arrive at a plausible result even when he wrestles with the unstructured task of modeling a system?)

-- Can more explicit guidelines for problem definition be designed? (Obviously, knowledge of the simuland is necessary in order to model; but in practice, an overly detailed knowledge often seems to paralyze the modeler. Is there an optimum amount of information most conducive to successful initial modeling?)

-- Is the identification of a reference mode an effective way of arriving at a fruitful problem definition for dynamic modeling? (Since behaviour modes are not (yet) commonly acknowledged by social observers in the media or academia, relying on a mode may unduly constrain the modeler to a small class of known types of phenomena.)

-- Is it reasonable to expect to be able to capture the causes of most extant dynamic behaviours within the boundaries of simple models? (In other words, is it feasible in most cases to identify only a few basic mechanisms with the expectation of still making a meaningful, simple initial model?)

-- Is it desirable to start by making a simple model based on insight, and then add further complexity to serve specific purposes, such as credibility? (Instead of starting with a complex model and then simplify.)

-- Is it desirable to start with a very high level of aggregation, then push down until the process of interest can be seen and studied?

-- Is generalized testing an efficient guide toward better models? Can the test criteria be improved or formalized?

-- How can the modeler unearth dormant negative loops which he has never seen actually operate because the simuland has never been pushed to the extreme before? (Alternatively, is it useful to ask why has the simuland never gone to an extreme before?)

-- Is it important to know the relationships between various structures and their behaviour, and, if so, what is an efficient and educative

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way of cataloguing structures and behaviours?

-- How does the modeler choose a set of levels (state variables) from the set of descriptive elements of the system?

-- What can go wrong in adhering to the modeling procedure recommended here?

-- Do the ten guidelines overemphasize certain aspects of modeling to the exclusion of other, equally important considerations?