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SIMULATION OF
VALUE-CONTROLLED DECISION-MAKING:
APPROACH AND PROTOTYPE

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August 1973

SIMULATION OF VALUE-CONTROLLED DECISION-MAKING: APPROACH AND PROTOTYPE

Hartmut H. Bossel and Barry B. Hughes

SUMMARY

The normative aspects of decision-making have to date only rarely been explicitly considered in modelling decision-making processes. In social processes, constant changes in values and goals have extremely important consequences on decision made. The simulation of such processes therefore cannot be successful without an understanding of normative systems and their change. The present report introduces the concepts of norms structure, content, and weight and considers the change processes of adaption, adoption, imposition, and diffusion. These concepts are made operational in a dynamic model of the norms stratum for energy policy decision.

After testing, the norms stratum is imbedded into a completely simulated decision-making process for the energy policy sector of the North American and Western European region. Policy choices are made by the model on the basis of a heuristic mixed-scanning approach to the policy search, and evaluation of the projected results relative to the changing goals of the system. The evaluation takes into account the different weights associated with the different components of the multiple-goal vector, discounted future costs, and instrument costs. Results given for different scenarios illustrate the utmost importance of including models of normative processes in simulation attempts of social systems.

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SIMULATION WERTABHÄNGIGER ENTSCHEIDUNGSFINDUNG: ANSATZ UND PROTOTYP

Hartmut H. Bossel und Barry B. Hughes

ZUSAMMENFASSUNG

Die normativen Aspekte der Entscheidungsfindung sind bisher bei der Simulation von Prozessen der Entscheidungsfindung selten explizit berücksichtigt worden. Die ständigen Änderungen von Werten und Zielen in gesellschaftlichen Prozessen haben aber äußerst wichtige Konsequenzen für die getroffenen Entscheidungen. Der Simulation solcher Vorgänge kann daher ohne ein Verständnis normativer Systeme und ihrer Veränderung kein Erfolg beschieden sein. Der Bericht führt die Begriffe Normenstruktur, Normeninhalt und Normengewicht ein und betrachtet die Normenänderung durch Adaption, Adoption, Imposition und Diffusion. Diese Vorstellungen werden in ein dynamisches Modell des Normenstratums für Entscheidungen auf dem Gebiet der Energiepolitik umgesetzt. Nach Überprüfung wird das Normenstratum in einen vollsimulierten Entscheidungsfindungsprozeß für den Sektor Energiepolitik der nordamerikanischen und westeuropäischen Region eingebettet. Das Modell wählt geeignete Maßnahmenbündel nach einer heuristischen Weit/Engsuche (mixed scanning) und Bewertung der zu erwartenden Ergebnisse im Hinblick auf die sich ändernden Ziele des Systems aus. Die Bewertung berücksichtigt die unterschiedlichen Gewichte der verschiedenen Komponenten des Mehrzielvektors, diskontierte zukünftige Kosten und Umstellungskosten. Die für verschiedene Szenarios vorgelegten Ergebnisse zeigen, welch außerordentliche Bedeutung dem Einbau von Modellen normativer Prozesse in Simulationen gesellschaftlicher Prozesse beigemessen werden muß.

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1. VALUES AND DECISION-MAKING

Values quite clearly do underly all decision-making processes -- the determination of " who gets what, when, and how"[1] requires normative judgments concerning people, concerning goods and services distributed to those people, and concerning means by which decisions are made and benefits are allocated.

1.1 Decision-making

Simulations of decision-making thus inevitably must deal with normative issues. This is, of course, widely recognized in the decision-making literature.[2] The response to this recognition, however, has not been completely satisfactory. In general there have been two approaches to the introduction of norms or values into general decision-making frameworks or theories and into simulations. First, in most of the decision-making literature itself there has been what might be termed "implicit value treatment". For instance, decision-making theories built around concepts such as " satisficing " and " incrementalism " are explicitly concerned with certain decision-making process values such as effectively using information (or acting given a scarcity of information) and maintaining low decision-making costs. Yet with the exception of monetary costs, these theories largely ignore the question of more general values which shape policies. This is reasonably justifiable in a shortterm, incremental situation when a decision-making model is designed to initially make policy similar to the policy currently in actual use. Such a policy obviously does reflect the norms of the real-world decision-makers and thus implicitly brings them into the model. Moreover, in the short-run it can usually be assumed that relatively minor norm or value changes will occur, so that a model of policy-making structured to produce minor variations from the initial policy can be quite satisfactory.

However, when we turn our attention towards longer-term decision-making, especially within a context of fairly major environmental changes which both constrain decision-makers and affect their values, implicit introduction of values is insufficient. Moreover, most decision-making situations (excluding situations such as a chess game where winning is the primary goal or a firm where profit is the dominant motive) represent complex multi - value problems which require the explicit introduction of specific values. Most political decision-making certainly falls into this class.

1.2 Values

Growing out of the rapidly increasing literature concerned with the future and the solution of major societal problems is a sub-literature which is explicitly concerned with the role of values in the decision-making process. For instance, the Harvard University Program on Technology and Society under the direction of Emmanuel Mesthene has oriented several of its research reports toward the interrelationships between values, technology, and the future.[3] Similarly, there has been some effort to develop frameworks in which values and their change can be systematically studied.[4] For the most part, however, approaches remain at a very high level of generality, including some efforts to list major values and discuss their change over time and efforts to outline the interrelationships (hierarchies and dependencies) among values and the process of change.

1.3 Problems of coupling

There has been, however, no case in which a systematic approach to values and value change has been coupled with a simulation of decision-making processes. In fact, the treatment of values has been much more qualitative than the treatment of decision-making -- apparently values are perceived as even more fuzzy variables.[5] Since there is such a strong case for coupling values and the decision-making process, and since such a coupling is the subject of this report, it is worthwhile to review some of the reasons for the absence of efforts.

One major reason lies in the inadequacy of theoretical approaches for dealing with the critical issue of norm or value change.[6] Irene Taviss points to three different possible theoretical approaches.[7] The first sees the driving force behind social value change in changing social conditions, such as changing technology. Future Shock[8] might illustrate the development of this general notion. Taviss feels that this approach has limited utility in predicting future values because of the lag between social change and value change. Taviss suggests that a second approach is imbedded in Rescher's notion of " modes of value change ", in which he strongly emphasizes hierarchies of values which affect each other. Finally, Taviss proposes that the most practical route to the prediction of value change involves examining the gap between present social conditions and present values, and then assuming the values will adapt to the social structures. It seems clear, however, that none of these approaches represents more than a sketchy and incomplete outline of the important mechanisms. We will return in more detail to the question of value change.

Many other problems have delayed the explicit introduction of values into decision-making simulations. Among these are the cross-cultural differences among values. We will need to focus explicitly on different culturally-bound sets of values. Another critical issue lies in the difficulties in specifying trade-offs among values.[9] Still another is the fact that societies are heterogeneous and that any detailed specification of values (as completely as required for a simulation) must be peculiar to at most one group within the society.[10] And still another problem is obtaining the necessary quantitative measures of the values. Techniques such as surveys or content analysis not only introduce the probability of mismeasurement, but also of error as a result of misrepresentation of values by respondents or sources of content analysis documents.

1.4 Overview of report

We should not underestimate or ignore any of the problems noted above. This report will address itself to all of them. We will first look at the general structure of the approach suggested here and discuss the more general context of the project. We will then discuss more specifically the structure of the value or norms component of the model and how it affects specific goals of decision-makers. We will then describe a decision-making process built upon these changing goals. The next step will be to present and discuss a working prototype of the complete norms-goals decision-making process for energy problems of the developed world. Finally we will note some of the work which remains to be done.

Footnotes and References to Section 1

[1] Harold Lasswell in a phrase which has become the standard definition of politics.

[2] The failure to adequately consider values is criticized severely by David L. Johnston and Arthur L. Kobler, " The Man-Computer Relationship," Science, 138 (November 23, 1962), pp. 873-9.

[3] See the bibliographic reviews in Harvard University Program on Technology and Society, Research Review No. 3, Technology and Values, Cambridge, Mass., 1969.

[4] Nicholas Rescher, "What is Value Change? A Framework for Research, " in Kurt Baier and N. Rescher, eds.,. Values and The Future: The Impact of Technological Change on American Values (New York : Free Press, 1969); Hartmut Bossel, " Notes on Simulation of the Norms Stratum and Norms Adjustment for Multi-Echelon Processes," Institut für Systemtechnik und Innovationsforschung, Karlsruhe, Germany, February 1973.

[5] R. E. Bellman and L.A. Zadeh, " Decision-Making in a Fuzzy Environment," Management Sciences , Vol. 17, 1970, pp. B-141-B-164

[6] Fred Charles Ikle, " Can Social Predictions be Evaluated?" Daedalus, 96 (Summer 1967), pp. 733-762.

[7] Irene Taviss, "Futurology and the Problem of Values," Harvard University Program on Technology and Society, Reprint No. 12

[8] Alvin Toffler, Future Shock (New York: Random House, 1970)

[9] Many individual situations of the problem have been noted, including Harold R. Walt, " The Four Aerospace Contracts: A Review of the California Experience, " _Applying Technology to Unmet Needs_, Appendix Volume V to National Commission on Technology, _Automation, and Economic Progress, Technology and the American Economy_ (Washington, D. C.: U.S. Govt. Printing Office, 1966).

[10] Karl Mannheim, _Diagnosis of Our Time_ (New York: Oxford University Press, 1943), esp. Chap. 2, "Crisis in Valuation," pp. 15-34.

2. GENERAL CONTEXT OF THE PROJECT

A decision-making model requires at least three elements:

1. An environment in which problems arise and in which decisions are implemented.

2. A general structure of the decision-making process including information reception, alternative consideration, evaluation, and choice.

3. A normative element by which the evaluation and choice can be made.

The Mesarovic-Pestel World Model Project to which this report contributes contains all of these elements in a multilevel hierarchical structure.[1] Fig. 2.1 shows the general organisation of the model. The bottom four boxes (including the large center one) constitute the environment of the decision-maker (geophysical, ecological, technological, and causal aspects). These elements have been discussed elsewhere.[2] The "Organization and Decision-Making" Box represents the position of the general decision-making mechanisms within the model -- we will return to that. Finally, the top two layers of the figure show two general approaches by which the normative element can be introduced into the model.

In general, the user (upper right hand corner) can introduce norms either by his interactive use of the model or by his adoption of a mode in which norms are fully simulated. Actually, this is an overly simplified view of the ways in which norms can be introduced. We can conceive of five possible modes of operation for the model, with the norms stratum provided in varying degrees by an interactor and by a completely specified layer of the simulation.

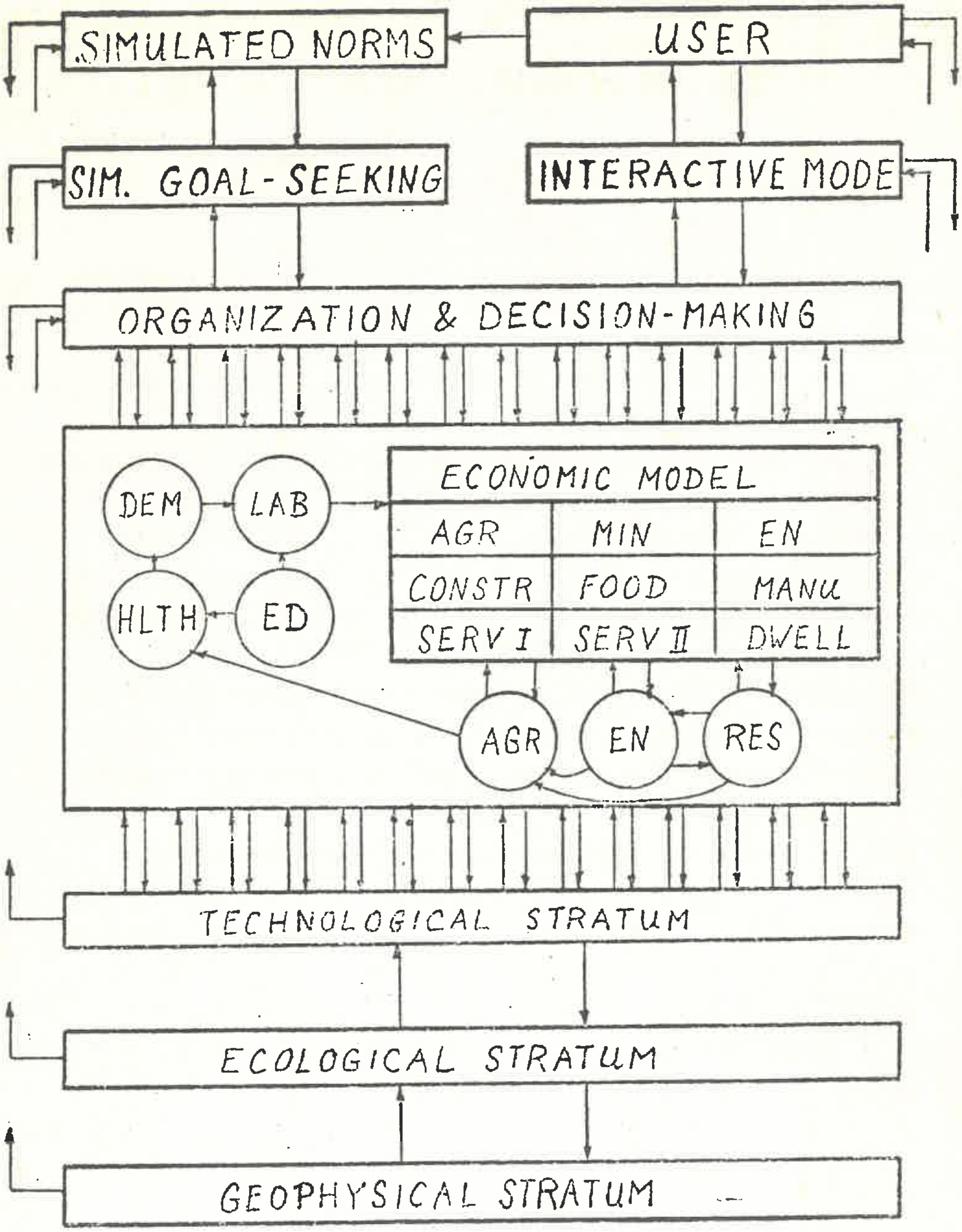


Fig 2. 1 - General Organization of the Mesarovic-Pestel World Model Project

Fig. 2.2 - Modes of Operation for the M-P Decision Units

Man-Machine Mix	Norms Supplier: Program	Norms Supplier: Interactor
All Machine	Complete machine simulation, using the norms supplied by the program	Policy-makers could see implications of their values (or those of others) worked out in to long run
Machine-Evaluation Aid	Interactors would receive some aid to policy evaluation from the norms supplied in the program.	Interactors would receive some assistance in policy evaluation in terms of norms of their own choosing.
All Man		Completely interactive

Fig. 2.2.represents these five modes of operation as the intersection of two dimensions. The first dimens ion distinguishes between the interactor and the simulation as two alternative suppliers of norms. It is desirable to give the decision-maker the option of having policies made or evaluated for him by our norms stratum submodel (which generates norms that we believe to be quite realistic), or allowing him to choose norms of his choice. The second dimension contains three different man-machine mixes for actual decision-making:

1. All machine simulation. Here no interactor would be necessary. Present and future values would be determined by our norms stratum submodel unless the model user wished to experiment with others.

2. All man interactive use. In this mode no societal values would restrict the interactor, nor would any procedural constraints. Clearly, only the interactor's norms would be important here.

3. Evaluative aid to interactive use. Many interactors would appreciate having some evaluative feedback on their policy, while maintaining their freedom to act and to accept or reject feedback. This mode could provide two types of feedback. The first type derives from the values or norms within the norms stratum submodel. The interactor would be told when he was considering a policy which significantly violated one of the norms. The second type of evaluative feedback would allow the interactor himself to set goals reflecting his norms. He would then have his policies evaluated in terms of his own norms.

It is, of course, necessary that we maintain both all-machine and interactive modes (and mixtures). When the model incorporates many regions and sectors of interest to decision-makers (population, environment, energy, etc.) it will be physically impossible to continue completely interactive procedures, even with multi-terminals and interactors. For policy evaluation purposes a user might select one or more areas (either geographic or issue areas) in which he will make policy, while deciding to let the rest of the simulation run in the all-machine mode. This contrasts with the gaming mode of model use in which several interactors operate as decision-makers for various regions or issue areas. Different modes of operation will, of course, also serve slightly different purposes. The gaming mode might be extremely useful for analysis of various futures scenarios, while the use of one interactor might be of most value for decision-makers themselves, and the all-machine use of the model might function to spotlight to most likely future problems.

Footnotes and References to Section 2

[1] Mihajlo Mesarovic and Eduard Pestel, " A Goal-Seeking and Regionalized Model for Analysis of Critical World Relationships -- The Conceptual Foundation," Kybernetes Journal , Vol. 1, 1972

[2] See especially the report of the World Model group on the structure of an economic model, M. Mesarovic et. al. An Implementation of the World Economic System Model , Multilevel World Model, Case Western Reserve University, Report No. 4, Systems Research Center, July 1973

3. NORMS STRATUM: STRUCTURE AND CHANGE

3.1 Introduction

Decisions cannot be made without reference to a normative component. Even if a decision-maker leaves a decision to the toss of a coin, he has applied the norm that the outcome does not really matter to him one way or the other.

In the light of this simple truth the present state of research on the normative part of decision-making is only somewhat less than deplorable. Concepts which could be applied to day-to-day decision-making outside of the economic area are almost nonexistent. The researcher trying to simulate a complex decision process realistically - in our case - finds a problem he cannot circumvent and must be excused for trying to solve it with limited and perhaps inadequate means.

The model of the norms stratum which we here propose and apply to the simulation of energy policy decisions is based on a concept formulated originally at the suggestion of Prof. Mesarovic.[1] The present version has benefitted from a study of the relevant literature. We found the volume edited by Baier and Rescher particularly helpful.[2] It contains a comprehensive bibliography on the subject, with references to additional bibliographies. Likewise the efforts of the Harvard University Program on Technology and Society have been of some help.[3] The writings of Jant sch, Vickers, and Bauer have also had an influence on our work.[4]

Formal models of the normative system have previously been proposed by Davidson el al., Smith, Anderson, and Rescher, among others.[5] These models, however, are either quite abstract or highly verbal, and cannot be directly used for computer implementation. Our present concept incorporates the important structures and mechanisms identified by earlier authors: in particular, one will find the notions proposed verbally by Rescher[6], such as value change by subscription, acquisition and abandonment, redistribution, emphasis and de-emphasis, rescaling, redeployment, restandardization, retargeting, and upgrading or downgrading, and the important concept of costs and felt benefits of maintaining a value (which are here expressed as a 'weight').

The normative system contains the collection of values, goals, norms, beliefs, standards, preferences, priorities, expectations, oughts, musts, constraints, attitudes, purposes, rules, laws, and regulations and other such quantities that are used as reference quantities in decision-making.

Any particular decision-making task requires a particular collection of normative quantities. We perceive this collection as being hierarchically ordered, with values (giving an overall direction to the decision-making effort), at the top, general goals (determined from values and controlling policy choice) somewhere in the middle, and operational goals or norms (derived from general goals and controlling individual decisions) at the bottom, i. e. at the interface with the decision stratum.

As a sharp distinction between values, goals, norms, and related concepts cannot usually be made, and would not be helpful in the context of the present section, we will (in this section only) refer to all members of the collection of normative quantities as 'norms'. In the following section we will again distinguish between values and goals. These norms are ordered in a hierarchy having a wide base and narrow top. Norms of increasing concreteness are found by going down the hierarchy, norms of increasing generality by going up.

In the following subsections, we will first discuss the nature of norms, i. e. the fact that they are generally given as 'fuzzy' verbal variables and that they are characterized by location in the norms structure, by state (or content) of the norm presently held in a given location, and by weight attached to the norm as the result of cost-benefit considerations.

All norms and their characteristics are subject to dynamic change.

Next, the structure of the norms stratum will be discussed. As the norms themselves, the structure is also a 'fuzzy' concept and subject to dynamic change. An attempt is then made to describe the different mechanisms of change processes in the norms stratum, with an eye towards implementation in computer simulations. At the interface with the decision-making process, the weights of norms turn out to be as important as their actual states. The concept of weight is therefore discussed briefly.

Measurement and representation of norms and of the normative structure pose the major problems in simulating the norms stratum. Possible approaches are considered. Some consideration is also given to the fact that the norms stratum is probabilistic and not deterministic in nature, and to corresponding implications for simulation attempts.

All discussions of the norms stratum in this report refer to the norms stratum of the de facto decision-maker. The de facto decision-maker may be evident only by his actions and may bear little resemblance to physical or organizational decision structures.

3.2 The nature of norms

> " Values and norms ... are terms of unusable vagueness today not because they cannot be usefully defined, but because they have not yet been sufficiently analyzed, although an abundant store of accessible fact is available for the purpose."
>
> (Geoffrey Vickers, in "Values, Norms and Policies", Policy Sciences 4 (1973), p. 103 f.)

Our analysis of the norms stratum is based on the following propositions, which will be explained below:

- Norms are characterized by location in the normative structure, by content (state), and by weight.
- The quantities characterizing norms (location, content, weight) and the dynamics of norms change are fuzzy concepts.
- Inconsistencies within the norms stratum (with respect to structure, content, and weight) will tend to be minimized.
- Norms contents are generally expressed as verbal statements.
- Norms contents and structures generally change by discrete amounts.
- As relative norms weight decreases, the relative uncertainties associated with norms location, content and weight increase.

Norms are characterized by location in the normative structure, by content (state), and by weight

Location: The structure of the norms stratum can be considered as a fuzzy graph. (The concept of fuzziness is discussed below.) At a given node of this graph, a norms statement on a particular subject is expected. The location thus defines the subject of the particular norm. In the example of Fig. 3. 1 the node presently having the norms content "waste not, want not" clearly is a node in which some statement about conservation of resources is expected.

The location of a norm is uniquely characterized by the neighboring nodes, some of which will carry superior, and others inferior norms. The lowest positions are occupied by the operational norms which guide and control the decision-making process.

Content: The statement presently active at a given node is referred to as the content or state of the norm. This content is subject to change. In the example, the norm on resource conservation could perhaps have the content "a little waste doesn't hurt" at some other time. The content can

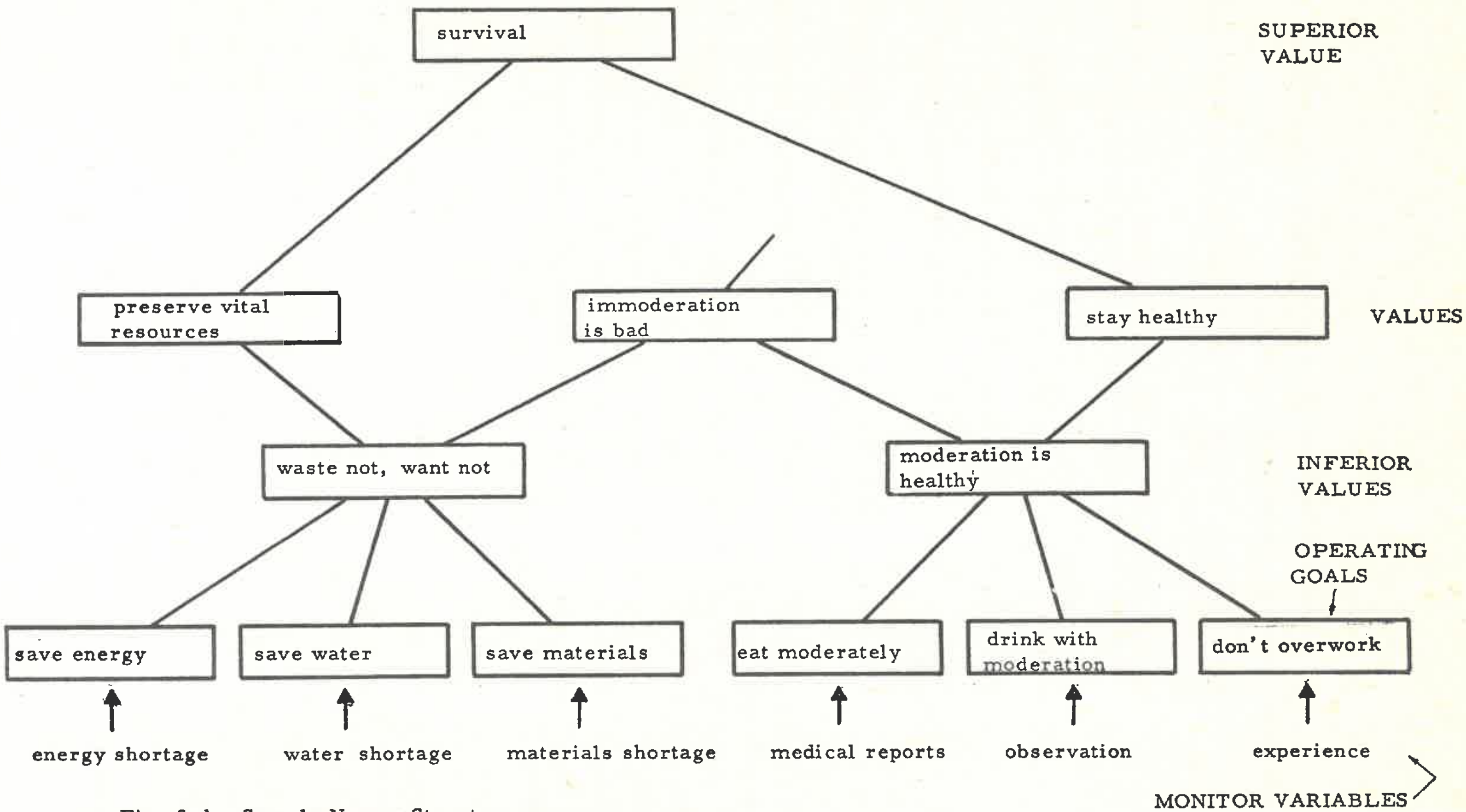


Fig. 3.1 - Sample Norms Structure

be viewed as the state of a continuous or discrete variable representing a spectrum of possible norm contents.

Weight : While the hierarchical norms structure and the contents can be obtained without referring to weights, the decision process requires that weights be assigned to all (operational) norms which directly interface with the decision process - if in the decision process reference must be made to more than one operational norm at the same time. The weights order the operational norms according to their importance to the system. The weights are subject to dynamic change as a result of changes in superior norms and of real or imagined costs and benefits derived from holding and applying a certain norm. The superior norms affecting weight and changes will not in general be neighboring superior norms defining the location of the norm in the norms structure. Instead, we can think of a separate weight structure superimposed on the norm structure (Fig. 3.2).

> Example: A society may hold the superior norm "all men are created equal" and the corresponding inferior and operating norms (laws) unchanged for a long period of time. If in decision processes demands are made on only one operational norm at a time, the case is decided (ideally) by referring to the laws on the books. If, however, in complex political multi-goal decision-making several operating norms have to be considered at the same time, different weights of these norms at different times will give rise to quite different decisions about comparable issues.

Weights can only be assigned with reference to the real or imagined costs or benefits of holding and applying certain norms. In general, the assigning of weights will be an iterative and adaptive process.

The quantities characterizing norms (location, content, weight) and the dynamics of norms change are fuzzy concepts.

Neither norms location (i. e. normative structure) nor norms content, nor norms weights, nor norms change dynamics can be determined exactly.

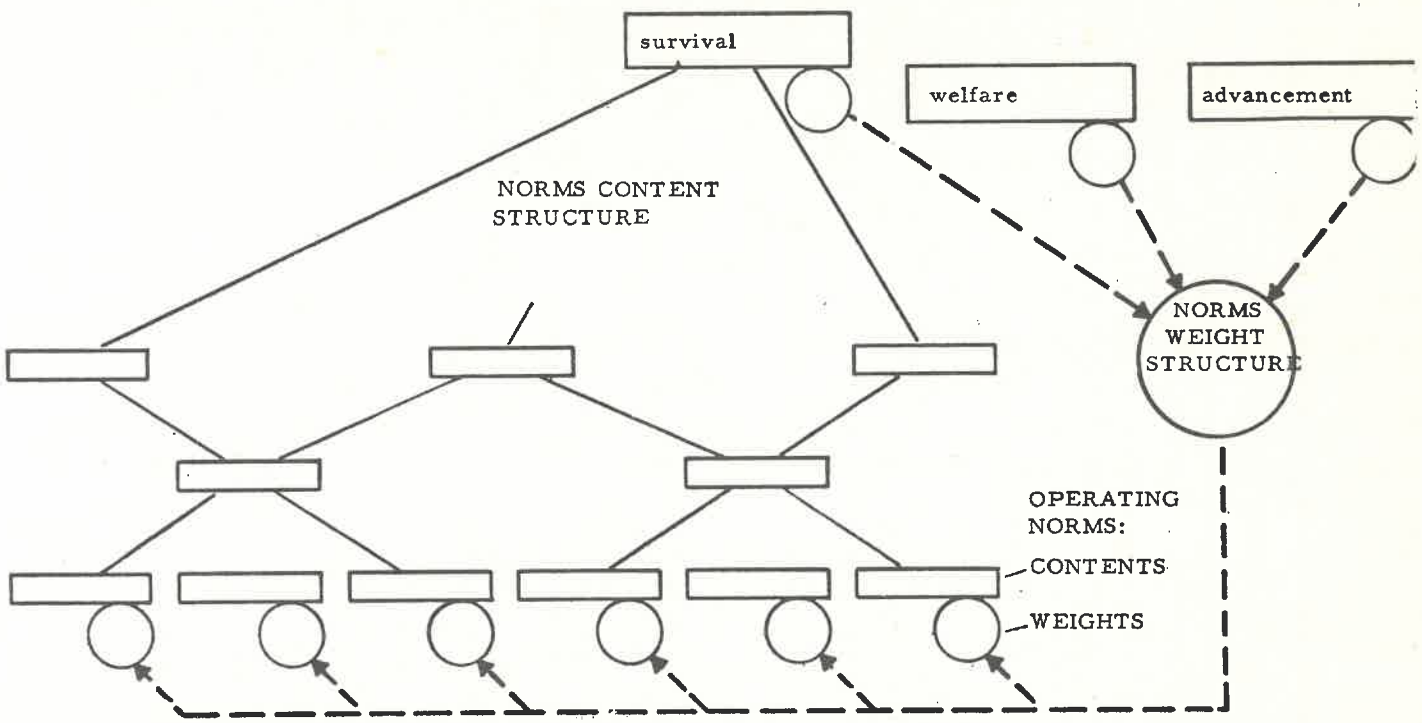


Fig. 3.2 - Weight Structure Super-Imposed on Content Structure

A person may be able to say, with considerable certainty, that his concern about pollution is 'moderate' or 'high', but neither he, nor anyone else, will be able to measure this concern to several digits on any scale. At best, a band can be given which represents the value.

The norms structure, contents, weights, and change processes (dynamics) are thus fuzzy concepts. They cannot, as a matter of principle, be determined with the accuracy of, say, macroscopic physical variables. They resemble a badly focussed photograph: darker and lighter areas can be seen, shapes and contours are vaguely discernible. The information content of the picture is nonzero: there is "something there", although some interpretive effort may be required before the image, or part of it, can be recognized. Recognition is achieved by projecting mental images of familiar things onto the unfocussed picture and comparing until reasonable agreement is achieved. We here proceed in the same fashion to extract a likely structure, norms contents, and norms weights from fuzzy evidence.

Fuzzy sets and fuzzy systems have attracted considerable interest lately as a result of the realisation that issues such as those of the present work cannot be treated in the manner of physical or engineering systems. We refer in particular to the work of Zadeh and others.[7] Progress made in this area will greatly aid efforts such as the present one.

It is important to point out that the concept of fuzziness should not be confused with the concept of probability. An unfocussed photograph is completely deterministic - except for the probabilities associated with different interpretations by different subjects. While a probabilistic variable takes on a well-defined and (in principle) precisely measurable value at each point in time, a fuzzy variable never takes on a precise value.

Inconsistencies within the norms stratum (with respect to structure, content, and weight) will tend to be minimized (consistency principle).

An important property of norms strata appears to be their strong tendency towards internal consistency with respect to structure, contents, and weights. If new norms are developed from existing norms, the new structure and its contents and weights will reflect the previous situation. If new norms are introduced as a result of trial-and error processes, outright unreflected adoption or imposition, these norms cannot remain in isolation and must eventually be tied to the rest of the norms structure in some consistent manner. If this is not easily possible using lower level norms, higher e.g. (religious) values will be brought into play (e.g. Jewish and Moslem food laws). Changes of the newly introduced norm and of neighboring superior and inferior norms can be expected until norms conflicts have been reduced to a minimum and neighboring structurally related norms have reached a certain measure of consistency.

The property of consistency can be used as a valuable aid in checking the plausibility of newly derived norms structures and of the contents and weights assigned to each node. It will likewise give an indication of what is likely to happen in the norms stratum after the isolated introduction (imposition or adoption) of a new norm.

Norm contents are generally expressed as verbal statements

In the decision-making processes of human societies norms must be clearly formulated, communicated, understood and followed by all parties concerned. Language is the common medium of communication; norms therefore usually appear as verbal statements. For computer simulation purposes, they will usually have to be translated into representative continuous or discrete variables. Natural language itself is a system of fuzzy symbols which do not carry the precision of digital representation, for example.

Norms content and structure generally change by discrete amounts

This observation follows from the fact that natural language can only express a finite number of discrete states. As a rule, a norm will only have a small number of discrete states (about two to nine). Most common is the Yes/No (True/False, Must/Must Not, One/Zero) type.

Where numerical values are involved in a norms statement, a more continuous representation of norms is possible. But even in this case norms will not be considered as distinct by the decision-maker unless they differ by (in some sense) significant numerical amounts.

As relative norms weight decreases, the relative uncertainties associated with norms location, content, and weight increase

As a particular norm becomes less important to a decision-maker, he is more likely to change it or even drop it as the result of stochastic influences. Probabilistic effects thus increase as the relative norm weights decrease. Thus, a system will generally attach the highest weight to the norm "survival", and can be counted on to apply this norm with a probability which borders on unity. When the weight of a norm is low, as for the case where a person is asked to decide between a pear and an apple for dessert, the probability of applying a certain norm (preferring the apple) also is low (a minimum of 0. 5 for apple and pear each). In simulations it is therefore advisable to attach probabilities to decisions which vary with the relative weights of the applied operating norms.

In the present case the operating norms carry sufficient weight and correspondingly high probabilities of application. It is therefore believed that the deterministic simulation used is a sufficiently accurate representation of reality.

3.3 Structure of the Norms Stratum

" Some general agreement ... can be found for the idea that values serve to shape goals, which in turn influence behavior, ... thorough explication of the mechanisms which link the three has generally not been attempted. Nor has much attention been paid to the dynamics of value formation, beyond the general idea that values are somehow related to life experiences and living conditions. In short, questions of the nature of values have, by and large, been ignored by contemporary sociology."

(in Irene Taviss, "The technological Society: Some Challenges for Social Science," Social Research 35 (Autumn 1968), p. 537.

Decisions are determined by (1) the content of operating norms (operating goals) and (2) the weights of these norms (goals). These independent quantities are each derived through independent hierarchies originating in basic or derived norms. The two hierarchies - one for norms content, the other for norms weight - are independent of each other. Obtaining the structure of the norms stratum thus means obtaining a hierarchically ordered set of norms having a bearing on the given decision problem, and connecting them by two independent structures - one for the norms contents, one for the norms weights.

The example of Fig. 3.1 may elucidate this basic concept. The particular activity sector of the system considered here requires operating goals on the use of energy, water, materials, and standards on eating, drinking, and working. These goals are derived from two superior norms ("waste not, want not" and "moderation is healthy") which again have a common superior norm ("immoderation is bad"). The content of the operating norms is derived partly from superior norms, partly from the levels of monitoring variables such as (perceived) energy shortage etc. The weight attached to each of the operating norms, however, follows from the importance which each of the goals has to the desired functioning of the system. This desired functioning is a projection of basic and/or derived values; hence the weights of operating norms are determined directly by these values. In the example, the weights would be determined by the importance of energy, water, materials, food, drink, and work, respectively to the system. Note that abundance of water for example will have no effect on the importance of water to the system. Hence the weight of the norm on water use will not be affected. However, since water is now abundant, the respective operating norm on water use would now be relaxed (this is explained later), and despite the weight of the norm a smaller dissatisfaction signal would be generated upon its violation.

Decision-making organisms or organisations are "born" with only a rudimentary norms structures which appears to consist mainly of foundamental values "survival" and "reality adjustment" (perhaps also "welfare" and "advancement" as suggested by Rescher [8]). On this rudimentary foundation a more complex norms structure is eventually built in response to the day-to-day decision-making demands made upon the system. There appear to be two basic mechanisms for carrying out this task: (1) derivation of required operating norms in an ad-hoc manner from existing norms; and (2) trial adoption of plausible operating norms.

In the first case operating norms are derived ad hoc from the existing norms structure via smaller or larger hierarchies of values and goals (norms) as required by the activity sector for which a decision is required. This process of derivation of operating norms from existing norms ("deciding what I want to do") is relatively complicated and not well-suited for routine decision-making. Hence if the same or similar demand is made more often, the derivation of a particular operating norm will be replaced by recalling the operating norm obtained for this or a similar case. This norm, now internalized, will be used henceforth unless a revision is made. In this manner the system gradually builds up a hierarchical norms structure with the corresponding operating norms, based on earlier ad hoc derivation of operating norms from more basic norms, goals or values. The hierarchy and the number of operating norms thus grows with increasing variety of activities the system engages in, and the corresponding breadth of required decisions.

In the second case operating norms are determined by a trial-and-error procedure. In this mode operating norms are found iteratively by determining those that give satisfactory performance. In this case there will not be initially a hierarchical structure relating superior norms and values to the operating norms; however, it may be inserted later by rationalizing the choice. It is likely that such ex post facto rationalization is always possible and even necessary to keep the normative structure internally consistent.

The weights given operating norms are identical to the weights (i.e. 'importance') of the decisions to which they apply. The system will recognize the gravity of a decision before it searches for an applicable operating norm. This weight is determined by estimating the degree of violation of (basic) values resulting from a wrong decision. These values themselves have different weights. If the basic value "survival" is threatened by a wrong decision, the weight of a corresponding operating norm will indeed be very large; if the basic value "esthetics" may be violated, the weight of the corresponding operating norm will be relatively small. Weights of operating norms thus correspond to the weights of basic or derived values whose satisfaction a decision might affect.

Whether by derivation or by trial-and-error, the system in any case determines operating norms as required by the decisions it has to make and assigns weights to them. As a given operating norm is referred to more and more often, it will be added to the inventory of operating norms and will be used automatically. The experience of decision-makers can thus essentially be measured by how many operating norms for complex situations they have internalized.

The norms structure we now envision is shown schematically in Fig. 3.3 . The norms content structure is hierarchical with very few basic values at the very top, and a multitude of operating norms at the bottom. Within the structure, the basic values will connect to the operating norms via perhaps a large number of norms (values and goals) of decreasing generality and increasing concreteness. The resulting graph will only in rare cases be of the simple branch type; more generally, interconnections of different branches at various levels will occur (Fig. 3.4).

The weights of the operating norms are determined by a simpler graph relating mostly values of the upper part of the norms hierarchy to the operating norms (Fig. 3.3). A possible method of weighting consists of assigning to each node the sum of weights of the superior nodes directly connected to it.

Operating norms will be deleted from the norms structure when they are no longer needed in decision-making. The particular operating norm then has become irrelevant to the operation of the system and its weight has therefore dropped to zero - a statement which is identical to deletion of the norm.

3.4 Normative change processes

Norms at all levels may change at any time; they may also be added or deleted. There appearsto be a multitude of possible change processes which we will try to classify here. In addition there will be dynamic changes in the weights assigned to norms.

Some examples may serve to illustrate the possibilities[9]:

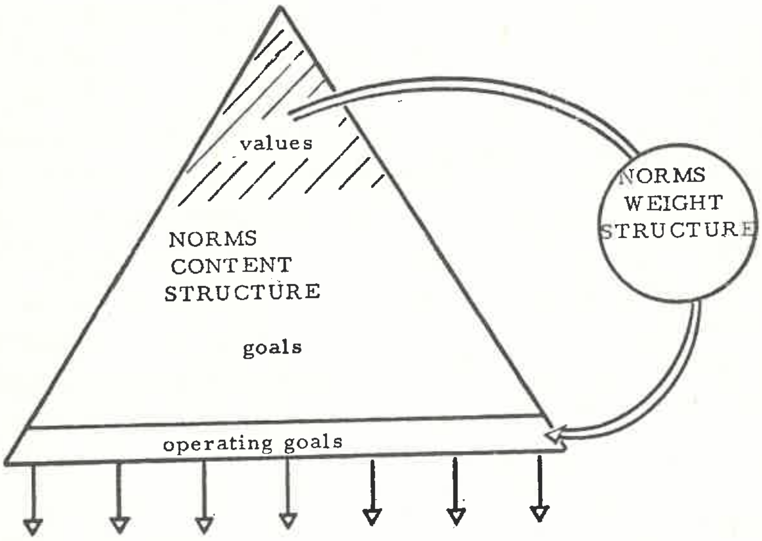
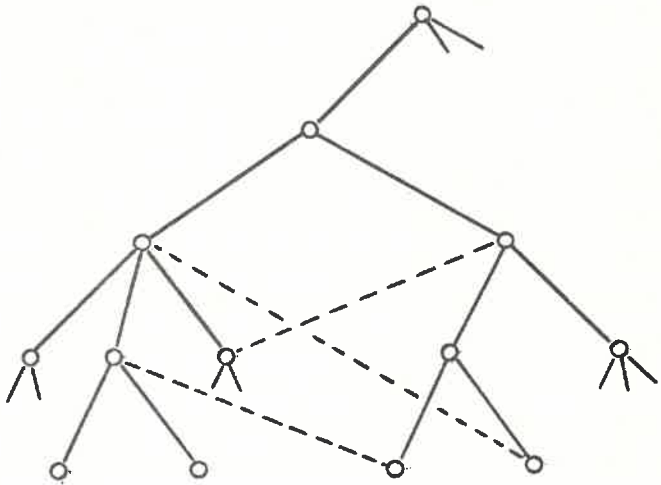


Fig. 3. 3 - Schematic of Norms Structure



———	Simple branching
- - - - -	possible interconnections

Fig. 3.4 - Branching Possibilities in Norms Structure.

An operating goal may turn out to be unattainable at reasonable cost - it will then be relaxed. Relaxing this norm may have effects on superior norms, which may also have to be relaxed to preserve consistency. Other inferior norms deriving from one of the superior norms may then also require revision, thus possibly affecting other operating norms quite unrelated to the norm which had to be relaxed in the first place. As another example, a society may decide that it wishes to adopt the principle of "higher education for everybody". The reasons for this may be partly societal wealth, partly greater needs for skilled people, partly a desire to insure "equal opportunity" for everybody, partly the observation of a reference society, and perhaps other reasons as well. As a consequence of the adoption of this principle, which represents a superior norm, a large part of the norms structure will have to be revised (reaching down to operating norms for school construction, teacher education, taxes, etc.) or perhaps will have to be newly introduced. As another example, a powerful institution may impose new norms which the decision-making system will have to obey whether it likes it or not. Again, substantial modification of parts of the norms structure may follow.

An example for changes in norm weights are the substantial changes in the importance (weight) of operating norms in the environmental sector as a result of reorientations of values concerning the environment.

The three possible modes of change of the norms stratum are

- change of the norms content
- change of norms structure
- change of norm weights.

These changes may come about as the result of four basic mechanisms:

- adoption
- adaption
- imposition
- diffusion

Through adaption, norms at any level are gradually adapted to changing conditions in the perceived environment of the system. Norms may also be adaptively introduced into, or deleted from, the norms structure. Adoption implies the conscious decision to adopt a new norm (or different content or weight), or a new set of norms. Imposition implies a norms change by an outside agent which the system by itself would not have undertaken at the present time. These mechanisms and their relationships to the causal stratum and the environment of the system are shown in Fig. 3.5 .

Once a norm has been changed, consistency will usually require corresponding changes in superior and/or inferior norms. Thus a young man who refuses induction into the military out of a concern for his survival will not only have to revise some of his superior norms concerning his attitude towards hi s nation and other countries, the government, and his parents, but will also have to modify some concrete operational norms governing his behavior in society. We therefore distinguish between

- upward diffusion (revision of superior norms), and
- downward diffusion (revision of inferior norms).

The four basic processes of norms change (adaption, adoption, imposition, diffusion) require a few more words of explanation.

Adaption: Changes in the environment of a system may result in changes in the norms (content, structure, and/or weight). Adaptive changes are made in response to perceived changes in the causal stratum and environment of the system as indicated by the monitor variables. These monitor variables do not usually represent the actual state of the environment; rather they characterize the output of a system of delays, filters, selection, bias and accumulation and threshold effects which modifies the information about the actual states of variables in the environment and causal stratum of the system. Adaption includes such processes as relaxation of goals, and gradual changes in values.

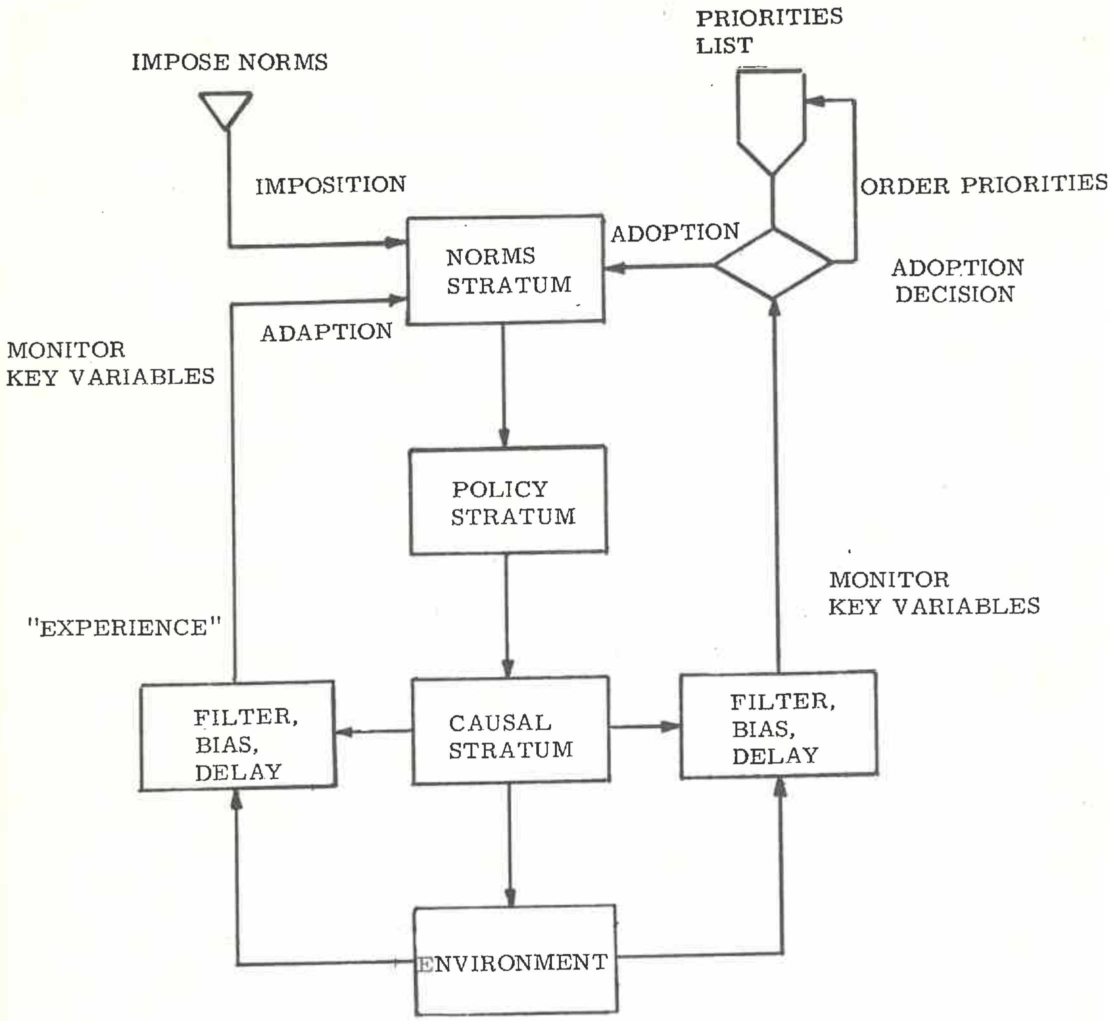


Fig. 3.5 - NORMS ADJUSTMENT PROCESSES

Adoption: In contrast, adoption implies the conscious change of an old norm or the planned introduction of a new one (with the necessary inferior and superior structure), or the willful change of norm weights. This process is again undertaken as the result of observation of monitoring variables (with their inherent bias, delays, filtering, etc.). In contrast to adaption, adoption therefore implies a conscious decision favoring the change. Usually it will take the form of adoption of a norm from a list of ranked priorities which the system keeps and modifies according to the circumstances it finds itself in with respect to environment and causal stratum. The norm will be adopted if the system 'thinks' it will be able to handle the consequences. The process of adoption thus requires a constant observation of system states and of the environment. A norm which has been found to be desirable is adopted when the opportunity arises.

Admittedly the distinction between adaption and adoption will occasionally be difficult to make and may often not be necessary, as adoption can also be interpreted as adaption, albeit on a higher (conscious and controlled) level.

Imposition: In contrast to adaption or adoption, the imposition of norms (change in structure, content, or weight) comes about as the result of interference by an external agent. The change will therefore usually be unrelated to the undisturbed natural development of the system and will be rather unpredictable. The system will either grudgingly accept and internalize the required change, or modify it as far as possible or eliminate it again at the first possible opportunity. An example are the norms and values imposed by occupational forces.

Diffusion: A change in a given norm by either adaption, adoption or imposition will seldom affect only that particular norm by itself. Rather, consistency will usually require the modification of both superior and inferior norms. These modifications may diffuse upward and downward in the norms hierarchy, changing other norms in the process. It is important to realize that the process is not unidirectional: after a superior norm has been modified by diffusion, for example, this change may necessitate the alteration of a different inferior norm by downward diffusion. An example of diffusion can be traced in Fig. 3.1 . If the norm "waste not, want not" is changed by either adaption, adoption, or imposition, this may result in a change, by diffusion, of both the inferior and superior norms. A change in the superior norm "immoderation is bad" is likely to also modify, by downward diffusion, the inferior norms concerning health.

3.5 Measurement of content and weight and representation of structure

If the structure of the norms hierarchy, the norms contents and weights, and the processes of change were easily and accurately measurable, the description and simulation of the norms stratum and norms change processes would have been attempted much sooner. As it is, structure, contents, weights and change processes are fuzzy concepts which exist only partially in more or less explicit, concrete form (laws, regulations, religious codexes and social rules, government plans and goals, etc.), but for the most part are vague and subjective concepts in the minds of people. An explicit theory of the norms stratum and its change, as represented by a computer simulation, requires that such vague, implicit, and subjective information be made explicit and that it be in some way quantified.

Society has only one applicable unit of measurement to deal with the problem: verbal expression. The concept of the "common language" implies that there is widespread agreement on the meaning of words, phrases, and concepts. These can again be used to communicate new concepts. Ideally, no information is lost, and the concept is transferred intact, with the accuracy with which it can be verbally expressed.

The concepts of the norms stratum and change processes must first be obtained in verbal form; verbal information must then be translated into computer-usable form. This process implies that fuzzy concepts in the minds of people must be transformed first into a representation using a fuzzy system of symbols (i. e. natural language), and next into an exact digital representation suitable for computer processing. It is clear that during this process information may get distorted or be lost; it is hoped that the basic concept which was to be expressed is transmitted essentially intact. Our model-building efforts therefore labor under a serious handicap: most of the things we do cannot be proved in any exact sense. Our tests must be (1) subjective agreement on issues, and (2) the comparison of simulated results with their measurable counterparts in the real system.

As we are trying to describe fuzzy concepts with fuzzy symbols, the precision of measurement must be compatible. In the work discussed in the next section, a nine-point scale is used to represent subjective values from "zero" to "extremely high". The resulting resolution of 1/8 of the maximum value is believed to be the maximum attainable in problems of this kind. Use of a finer scale would only give the superficial appearance of more precise measurement and description.

In problems of the present kind, it is possible to avoid the use of absolute scales altogether and to deal with relative quantities only. (The reason is that no quantities are involved which have to satisfy conservation principles). This greatly simplifies the process, as estimates on relative scales can be much more easily made and will show a much greater measure of agreement between subjects. For obtaining such subjective data, the survey and questionaire methods developed in the social sciences can be used. Relative scales can be employed to quantify all the necessary information about norms content, norms weights, change processes, and norms structure. Methods applied in the present work are detailed in the next section.

In addition to being fuzzy, most of the concepts (quantities) describing the norms stratum and its change also have probabilities associated with them. It has previously been pointed out that these (subjective) probabilities are functions of the particular norms weights; lower weight implies greater uncertainty that the norm is being applied. In the present investigation the (operating) goals carry sufficiently high relative weight and corresponding certainty that the exclusion of probabilistic concepts seemed justified, and norms stratum and change processes were described deterministically.

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4. PROTOTYPE NORMS STRATUM

4.1 General approach

The norms stratum for the energy policy simulation model incorporates the essential elements of the previous discussion. A block diagram of the simulation is shown in Fig. 4.1 .

State variables from the causal stratum and the environment of the system which are assumed to be relevant to the process of value change are continuously monitored. It is important to point out that only the perceived levels of these variables matter to the system. These may be quite different from the actual levels in the causal stratum and the environment, the difference being a function of information distortion (bias, filtering, exaggeration or information suppression, inadequate means of observation, willful distortion, selection, accumulation and threshold effects, etc.) and information delay. As the full causal stratum of the world region simulated (North America and Western Europe) and of the other world regions (i. e. the system environment) are as yet not available, the full monitoring process is at present replaced by prescribing certain time functions for the perceived monitor variables. A particular set of time functions for the monitor variables corresponds to a particular 'scenario' (e. g. increasing resource scarcity, or increasing pollution, etc.).

The values held by the norms stratum change partly in response to changes in the monitor variables. As a general rule, one monitor variable will influence several values, while a given value will be influenced by a number of monitor variables. These possibilities are here taken into account by using a matrix of influence coefficients relating each of the monitor variables to each of the values. The influence coefficients may be positive, negative, or zero.

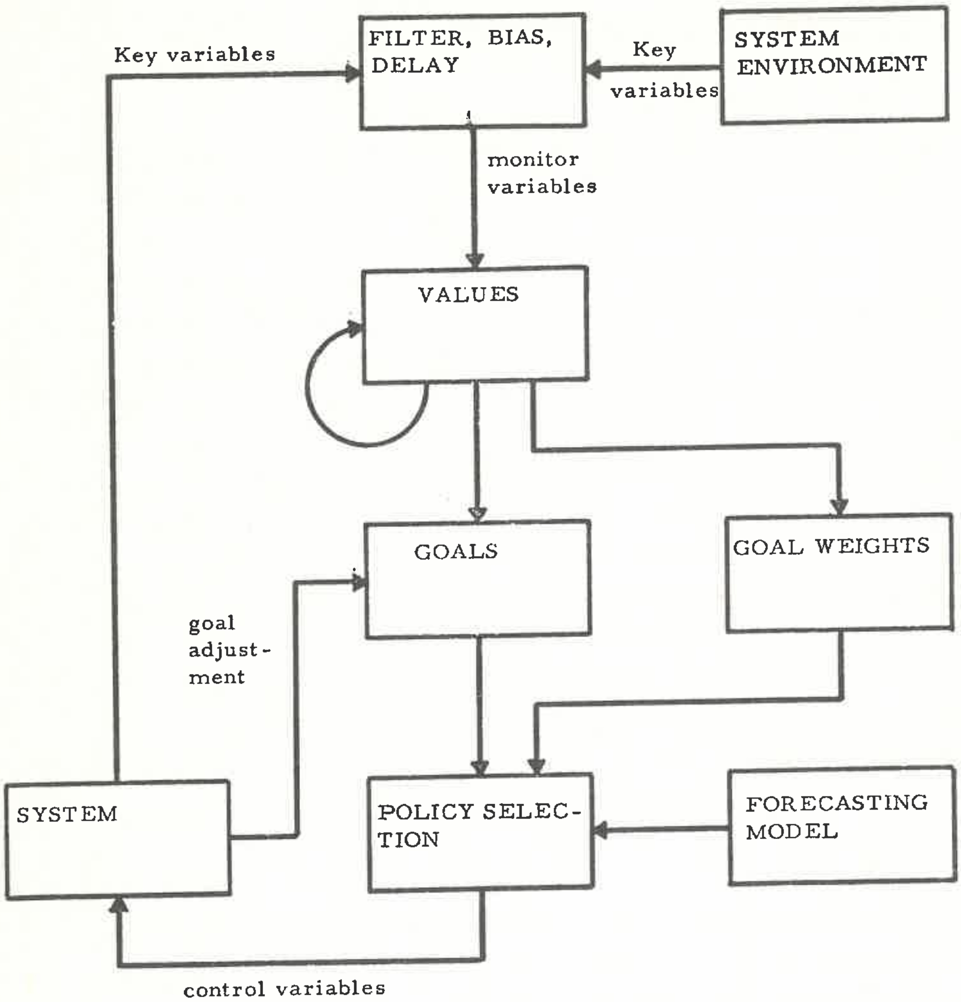


Fig. 4.1 - Block Diagram of Goal Adaptive Decision - Making Process.

In addition, values may change in response to changes in other values. This possibility is taken into account by linking all values with all other values through an appropriate influence matrix, where the influence coefficients on the main diagonal are now zero (a given value is not assumed to contribute to its own change).

The values are considered as state variables with given initial levels at the start of the simulation. These levels then change in the course of the simulation in response to the rates of changes in the monitor variables and in the other values. The new levels are computed by a finite difference summation. (Details are given below.)

The goals are also considered as state variables. They are again computed by a finite difference summation identical in form to that for the values, beginning with initial goal levels. As each of the relevant values may again, in principle, influence each of the goals, an influence matrix again relates each of the values with each of the goals. The values of the influence coefficients may again be positive, negative, or zero,

If the cost of reaching a goal becomes too high compared to the benefit obtained by reaching the goal, a relaxation of the goal can be expected. The present simulation incorporates a relaxation routine which is based on the magnitude of the gap between the goal and the projected state.

Decisions are always a function of goal value and goal weight. At a given point in time, the attainment of certain goals will be of dominant concern to the decision-maker to the detriment, if not neglect of other goals. Furthermore, the relative importance of different goals will change with time, as a function of changes in values. It is also well to remember that goal magnitude (content) and goal weight are generally quite independent of each other and will usually be determined by different values. Thus a change in goal weight will usually not be accompanied by a change in goal magnitude. At the present stage of our work we have not yet incorporated a goal weight change as a result of value change. However, the procedure would be not different than the simulation of goal change as a result of value change. Goal weights are now assigned as external parameters and remain constant during each simulation run.

Decisions can now be made by the system on the basis of the changing goals, the goal weights, and the projections about the future state of the system as obtained from the forecasting model. This decision process is described elsewhere in this report. The decision process changes certain control variables which control the causal stratum of the system (here mainly the economic sector of the region). Changes in the causal stratum and in the environment of the system then again influence the values through the monitor variables, thus closing the loop.

4.2 Implementation

The norms stratum interfaces with other strata (decision stratum, causal stratum) and the environment only through the monitor variables, the goals, and the goal weights. Hence it can be (and has been) separately developed once the general setting has been agreen upon. In the present case, the norms stratum was developed explicitly for integration into the interactive decision-making model for the energy sector of the North American and Western European region developed earlier at the Systems Research Center of Case Western Reserve University [1]. The norms stratum now replaces the implicit norms (values and goals) of the human decision-maker. The human decision-maker himself is replaced by the goal-adaptive decision-making process described later in this report. The contents of the norms stratum are thus determined by the possible range of decisions of the decision stratum: the norms stratum must be able to provide normative input for each and every possible decision which the decision layer can generate. This requirement determines all the goals and goal weights which the norms stratum must supply to the decision stratum.

In a subsequent step all monitor variables must be determined which can possibly affect values and hence goals. Furthermore, all relevant values must be determined. There is no exact procedure for this part of the investigation and no way to insure completeness. For the determination of both relevant monitor variables and relevant values the following procedure was used: after discussions, reflection, and the writing of 'typical' scenarios, extensive lists of possible monitor variables and values were drawn up. These lists were scanned repeatedly to exclude variables and values which were quite obviously irrelevant to the decision process at hand, to combine synonyms or antonyms as one quantity, to aggregate related variables, and to reduce the remaining variables as best as possible to what were felt to be more or less orthogonal sets of monitoring variables and values. Needless to say, if subsequent research should show that some important quantity has been overlooked its later inclusion is always possible. An identical procedure would be used in determining the monitor variables and values which affect goal weights.

Next the structural connections between monitor variables and values, values and other values, values and goals, and values and goal weights (here omitted) must be determined and quantified. This amounts to generating the structural graph of the norms stratum and specifying the functional relationships between its nodes. We have used influence matrices to relate the different sets of quantities: monitor variables to values, values to other values, values to goals. Since empirical data for the relationships between the different quantities are not available, all influence coefficients were determined subjectively. (For the mathematical nature of the influence coefficients, see discussion below).

The quantification required for the determination of the influence coefficients and also for the measurement of values and of the perceived levels of monitor variables, poses serious problems. Obviously most of the quantities cannot be measured in an exact sense; they are fuzzy and subjective variables. Nevertheless they can be expressed in verbal statements on a rather fine scale. We found that subjects were able to grade influence coefficients quite consistently on verbal scales, that these results were highly repeatable, and that there was a surprising measure of agreement between subjects. (As our investigations are exploratory, no exhaustive systematic studies were made on this point.)

Monitor variables, values, and influence coefficients (all are subjective fuzzy variables) could be positive, negative, or zero. They were graded on the following verbal scale (in parentheses the numerical equivalents used in the computation):

zero or extremely low	(0)
very low	(1/8)
low	(2/8)
between low and moderate	(3/8)
moderate	(4/8)
between moderate and high	(5/8)
high	(6/8)
very high	(7/8)
extremely high	(8/8)

The goal levels themselves were not determined in the norms stratum; its input to the decision stratum consists of yearly percentage changes for the individual goals.

The influence coefficients relating monitor variables to values, values to other values, and values to goals, were obtained from answers to questionnaires which required subjects to complete statements of the following type (example):

In my opinion, increasing perceived scarcity of resources and energy

will tend to increase	( )
will tend to decrease	( )
will have no effect on	( )
the general concern about the future	(Check one)

The magnitude of this effect will be

zero or extremely low	( )
very low	( )
low	( )
between low and moderate	( )
moderate	( )
between moderate and high	( )
high	( )
very high	( )
extremely high	( )
	(Check one)

The influence coefficients are determined by reading sign and numerical equivalents from these answers.

Since the setting of the imagined scenario affects the outcome, the statements were understood to apply to the present situation in the North American and Western European region. This also makes clear that some if not most of the influence coefficients are not immutable constants, but may rather change as a function of other state variables and time. This particular point has not been further investigated here; it will be the subject of future research.

It surprised us that influence coefficients derived from questionnaires completed independently by different subjects showed more agreement than we had hoped for. Fig. 4.2 gives an example of the estimated influence of 9 variables and 5 values on the value "concern about the harmful effects of pollution". In order to provide an independent check of the subject's estimate, we confronted him (about a week later) with a scenario and asked him to estimate resulting value changes. We then compared this estimate with the computed results obtained by

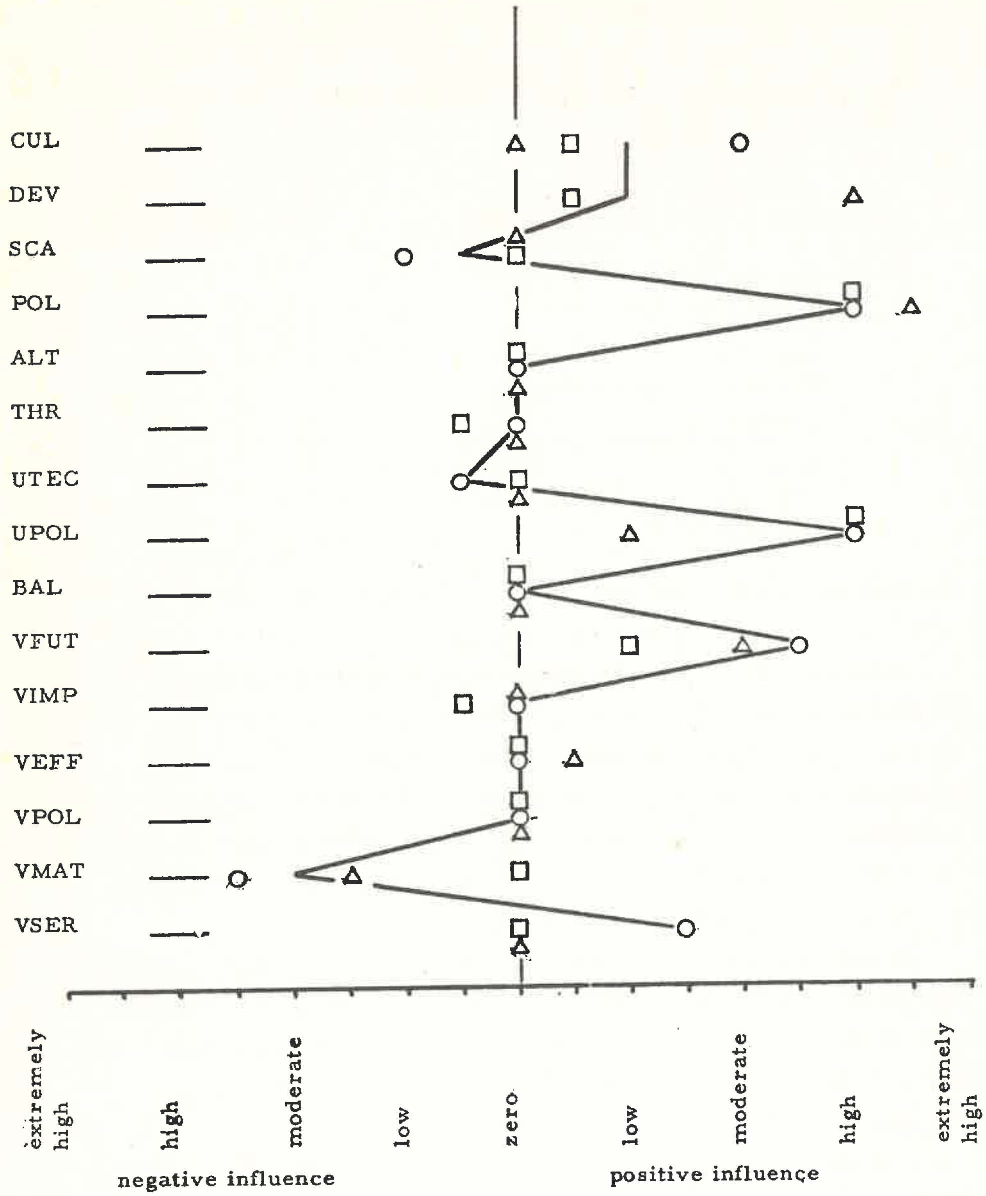


Fig. 4.2 - Estimates of Subjects A (o), B (□), C (△) of the Influence of Monitor Variables and Values on the Value VPOL (Concern About Pollution). Influence Coefficients Corresponding to Profile (—) are used in the Program.

applying the previously determined influence coefficients.

> Sample scenario:
> Assume that the perceived level of pollution rises from "moderate" to "high" in the span of five years.
> In your opinion, what value changes would result, if the initial values were all "moderate" (same scale as above)?

Fig. 4.3 shows the corresponding expectations of three subjects (A, B, C) and the computed values using the influence coefficients of subject A (wich agreed to a large degree with those of B, and to a lesser degree with those of C). The relatively good agreement between expected and computed results has an important consequence: we can expect that the computer model of values and goals change will quite faithfully represent the subject's intuitive assessment (as input by his influence coefficients) even in scenarios which are too complex for the subject to assess with any certainty (Example: While the consequences on values and goals of "increasing scarcity of resources and energy" can still be seen, those of a complex scenario involving different and time-dependent decreases and increases of the levels of, say, pollution, scarcity, industrial development, technological progress, external threat, and balance of payments will be impossible to assess in a way consistent with a subject's influence coefficients. A corresponding computer model based on these coefficients should still give a consistent assessment, however).

When comparing computed with expected scenarios, we found that influence coefficients had to be scaled down slightly (in the results presented here a factor 5/8 is used on all coefficients relating monitor variables and values to values) in order to make the two consistent. Apparently subjects exaggerate slightly when estimating influence coefficients.

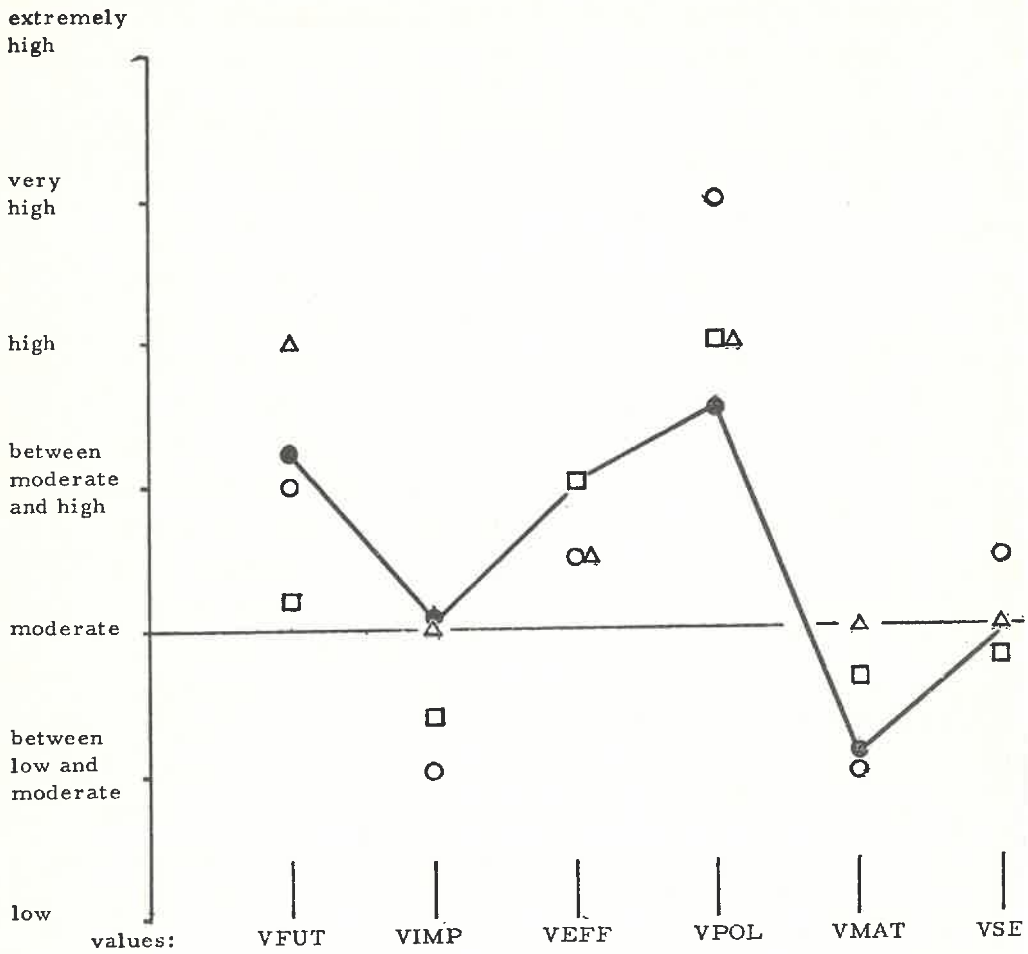


Fig. 4.3 - Expectations of Subjects A (o), B (□), and C (Δ) and Computed Prediction (——) for Value - Change Following a Scenario of Increasing Pollution.

Following the determination of influence coefficients and the running of consistency checks, the full program for the norms stratum was checked out by computing values and goals changes for a large number of scenarios (time variations of the different monitor variables) and checking the results against expectations. The results were deemed acceptable, and the norms stratum was then integrated into the goal-adaptive decision routine.

4.3 Details

Monitor variables

The following variables were identified as representing relevant monitor variables for the energy sector as represented in the present decision and causal strata:

- cultural orientation towards collective as opposed to individual welfare CUL
- level of industrial development DEV
- perceived scarcity of resources and energy SCA
- perceived level of pollution POL
- possibility of (technological, geological) alternatives (within the region) to imports of resources and energy ALT
- possibility of threat as a result of import dependence THR
- uncertainty about technological progress with respect to energy supply UTEC
- uncertainty about the harmful effects of pollution UPOL
- negative balance of payments BAL

With the exception of CUL, all variables clearly originate either in the causal stratum or the environment of the system. CUL (essentially a value) will in most cases be a constant, or a very slowly changing parameter. For this reason it was separated from the other values which can change much more rapidly.

Values

The following variables are assumed to represent relevant values for the given decision problem:

- concern about the future VFUT
- concern about dependence on imports VIMP
- concern about efficiency of resource and energy use VEFF
- concern about the harmful effects of pollution VPOL
- expectations concerning material standard of living VMAT
- expectations concerning service standard of living VSER

These values can be ordered (as becomes evident from the influence matrix relating values and goals) in a two-layer hierarchy, with VFUT representing a superior value. Other, even more basic values (such as survival, welfare, advancement, and reality-adjustment of the society [3]) could be added to this hierarchy, but they are here implicitly accounted for in the values given.

Goals and goal weights

The decision process requires the following goals:

- goal for energy imports GIM
- goal for gross regional product GGRP
- goal for industrial output per capita GYIPC
- goal for service output per capita GYSPC
- goal for energy consumption per capity GECPC

Obviously all goals but the first are dependent on each other. The hierarchical relationship between goals is shown in Fig. 4.4 . The goal weights must be assigned such that the sum of the weights of the subgoals at each layer equals the weight of the goal from which the subgoals are derived. To eliminate double-counting, only the goals in one layer of a goal-branch can be used. (Here one could use GGRP <u>or</u> both GYIPC and GYSPC, but not all three simultaneously). In all runs we have put the weight zero on GGRP (and GECPC), thus effectively using the goals GIM, GYIPC, and GYSPC. The goal weights assigned

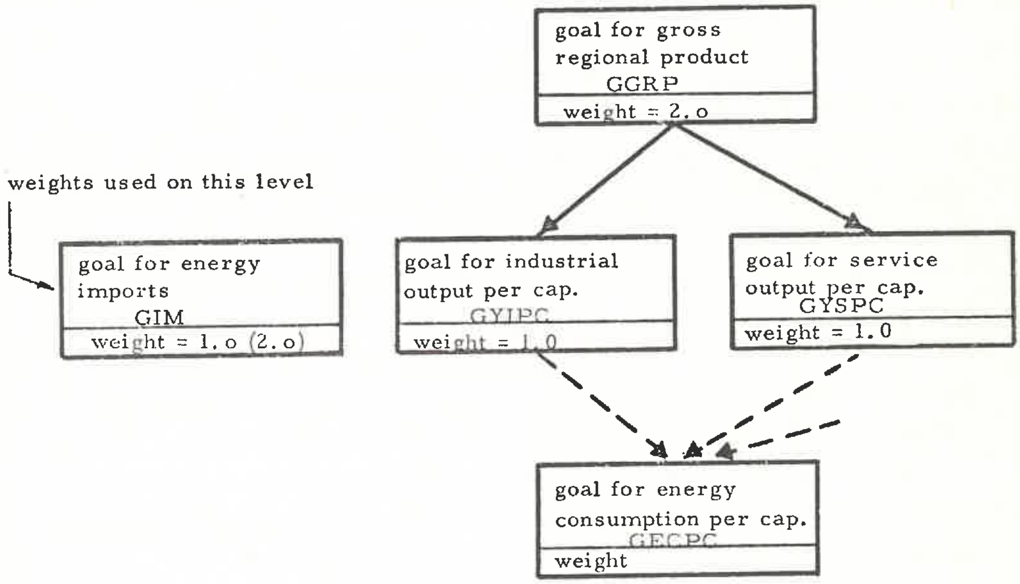


Fig. 4.4 - Goal Weight Structure

to these three goals were held constant during each computation, usually at a value of unity. For a scenario involving increasing threat due to dependence on imports, the goal weight for GIM was increased to the value 2. (See the section on the decision process for a discussion of the role of the goal weights in policy selection.)

Scales and units of measurement

All quantities in the norms stratum are measured on relative scales. With the exception of the goals, all of these quantities are subjective fuzzy variables and are measured on the 0-to-1 scale introduced earlier, ranging from a value of "zero or extremely low" (with a numerical equivalent of zero) to a value of "extremely high" (with a numerical equivalent of unity). The goals are measurable quantities (in monetary units or percentage annual growth rates). Monitor variables, values, and goals can here only be positive quantities, influence coefficients can be positive or negative (or zero).

The computation within the norms stratum actually only deals with rates of change in the monitor variables, values and goals. The computation of actual levels is incidental. Starting from initial goal levels, the decision stratum computes new goal levels on the basis of goal changes predicted by the norms stratum. Rates of change of monitor variables are measured in (units of the monitor variable on the 0-to-1 relative scale) divided by (units of time). The rates of change of values are similarly measured in (units of the value on the 0-to-1 relative scale) divided by (units of time), the rates of change of goals by (fractions of the goal on a percentage scale) divided by (units of time). This requires that the influence coefficients connecting monitor variables to values be measured in (units of the value being changed on the 0-to-1 relative scale) divided by (units of the changing monitor variable on the

0-to-1 relative scale). The goal changes are first computed on the 0-to-1 relative scale before being converted to percentage change. This means that the influence coefficients relating values to goals must be measured in (units of the goal being changed on the 0-to-1 scale) divided by (units of the changing value on the 0-to-1 relative scale).

Computation of value changes and goal changes

Values and goals are computed under the assumptions that (1) values are functions of the monitoring variables and other values; and (2) goals are functions of the values.

Let p_m ($m = 1, 2, \ldots, M$) be M monitor variables, q_k ($k = 1, 2, \ldots, K$) be K values, r_ℓ ($\ell = 1, 2, \ldots, L$) be L goals. Let the values q_k be functions of the monitor variables p_m, of other values q_j ($j \neq k$), and of time t. Let the goals r_ℓ be functions of the values q_k and time. Then the values can be written:

$$q_k = q_k (p_1, p_2, \ldots p_M; q_1, q_2, \ldots, \not{q_k}, \ldots q_K; t) \qquad k = 1, 2, \ldots, K$$

and the goals:

$$r_\ell = r_\ell (q_1, q_2, \ldots, q_k; t) \qquad \ell = 1, 2, \ldots, L$$

The respective time rates of change follow by differentiation. Time rate of change of values:

$$\frac{dq_k}{dt} = \sum_{m=1}^{M} \left(\frac{\partial q_k}{\partial p_m} \right) \frac{dp_m}{dt} + \sum_{\substack{j=1 \\ j \neq k}}^{K} \left(\frac{\partial q_k}{\partial q_j} \right) \frac{dq_j}{dt} \qquad k = 1, 2, \ldots, K$$

Time rate of change of goals :

$$\frac{dr_\ell}{dt} = \sum_{k=1}^{K} \left(\frac{\partial r_\ell}{\partial q_k} \right) \frac{dq_k}{dt} \qquad \ell = 1, 2, \ldots, L$$

The partial derivatives are recognized as the previously introduced influence coefficients. Let w_{km} be the influence coefficient relating monitoring variables p_m to value q_k, let v_{kj} be the influence coefficient relating value q_j to value q_k, and let $u_{\ell k}$ be the influence coefficient relating value q_k to goal r_ℓ. Then

$$w_{km} = \frac{\partial q_k}{\partial p_m}$$

$$v_{kj} = \frac{\partial q_k}{\partial q_j}$$

$$u_{\ell k} = \frac{\partial r_\ell}{\partial q_k}$$

The time rates of change of values are thus functions of the time rates of change of the monitoring variables and of other values, and of the influence coefficients relating monitoring variables to values, and values to other values. The time rates of change of goals are similarly a function of the time rates of change of the values, and of the influence coefficients relating values to goals.

The program uses finite difference approximation. The appropriate equations for the time rates of change of the values then become

$$\frac{\Delta q_k}{\Delta t} = \sum_{m=1}^{M} w_{km} \frac{\Delta p_m}{\Delta t} + \sum_{\substack{j=1 \\ j \neq k}}^{K} v_{kj} \frac{\Delta q_j}{\Delta t} \qquad k = 1, 2, \ldots, K$$

and for the time rates of change of the goals:

$$\frac{\Delta r_\ell}{\Delta t} = \sum_{k=1}^{K} u_{\ell k} \frac{\Delta q_k}{\Delta t} \qquad \ell = 1, 2, \ldots, L$$

Actually the rates of change thus computed are to be adjusted to account for the exaggeration effect in the estimation of the influence coefficients, and for the conversion of the goal rate of change from the relative 0-to-1 scale to the percentage scale required by the decision stratum. Thus the value rate of change actually used is

$$\left(\frac{\Delta q_u}{\Delta t}\right)^* = c_1\left(\frac{\Delta q_u}{\Delta t}\right)$$

and the goal rate of change

$$\left(\frac{\Delta r_t}{\Delta t}\right)^* = c_2\left(\frac{\Delta r_t}{\Delta t}\right)$$

In the present effort the numerical factors have been $c_1 = 5/8$ and $c_2 = 1$.

An important mechanism of goal adjustment is the relaxation of a goal if the cost of reaching it becomes too high if compared with the potential benefit. In the present simulation this mechanism has been incorporated into the decision stratum and is discussed there.

Influence matrices

The sets of influence coefficients are best represented in the form of matrices. They were obtained through questionnaires in the manner described earlier. The matrices now represent mainly the subjective judgment of one subject (A), modified after consideration of the results from two other subjects. It should be remembered that there are no 'right' or 'wrong' choices for the coefficients as they merely represent personal assessments of the interviewee. In a given problem, more representative values could be obtained by systematic sampling of large populations.

Table 4. 1

Influence matrix relating monitor variables to values (w_{km})

values q	k \ m	CUL 1	DEV 2	SCA 3	POL 4	ALT 5	THR 6	UTEC 7	UPOL 8	BAL 9
VFUT	1	6	3	6	4	-3	5	3	3	4
VIMP	2	0	2	6	-1	-5	7	3	0	6
VEFF	3	1	2	6	2	-2	5	3	1	1
VPOL	4	2	2	-1	6	0	0	-1	6	0
VMAT	5	-2	6	-1	-2	0	-1	-1	-1	-1
VSER	6	4	5	-1	0	0	0	0	2	-1

(monitor variables p)

(multiply entries by 1/8)

Table 4. 2

Influence matrix relating values to values (v_{kj})

values q	k \ j	VFUT 1	VIMP 2	VEFF 3	VPOL 4	VMAT 5	VSER 6
VFUT	1	0	3	3	4	-2	-1
VIMP	2	2	0	0	0	-2	0
VEFF	3	5	2	0	1	-2	0
VPOL	4	5	0	0	0	-4	3
VMAT	5	-1	-1	-2	-2	0	2
VSER	6	0	0	0	2	4	0

(values q)

(multiply entries by 1/8)

Table 4.3 -

Influence matrix relating values to goals (u_{fk})

values q / goals r	k / f	VFUT 1	VIMP 2	VEFF 3	VPOL 4	VMAT 5	VSER 6
GECPC	1	0	-4	-3	-2	3	2
GIM	2	0	-7	-1	0	2	0
GYIPC	3	0	0	-1	-2	6	3
GYSPC	4	0	0	0	-2	3	7
GGRP	5	0	1	-1	-1	5	3

(multiply entries by 1/8)

Computing program

The essential components of the norms stratum simulation have now been discussed. A flow chart for this subprogram is given in Fig. 4.5; the program listing is found in the appendix.

At the beginning of a simulation run, monitor variables, values, and goals are set to the initial levels. In a given year, the program then begins by obtaining the changes over the past year in the appropriate monitor variables. In the present experimental simulation, all monitor variables are computed from functions generated externally. These constitute a scenario for the system. In later stages of development, all monitor variables will be directly tied to the causal stratum and the environment of the system.

Next, rates of change over the past year in the monitor variables and in the values are used to compute the new rates of change for the values via the influence coefficients w and v. Finally, the rates of change

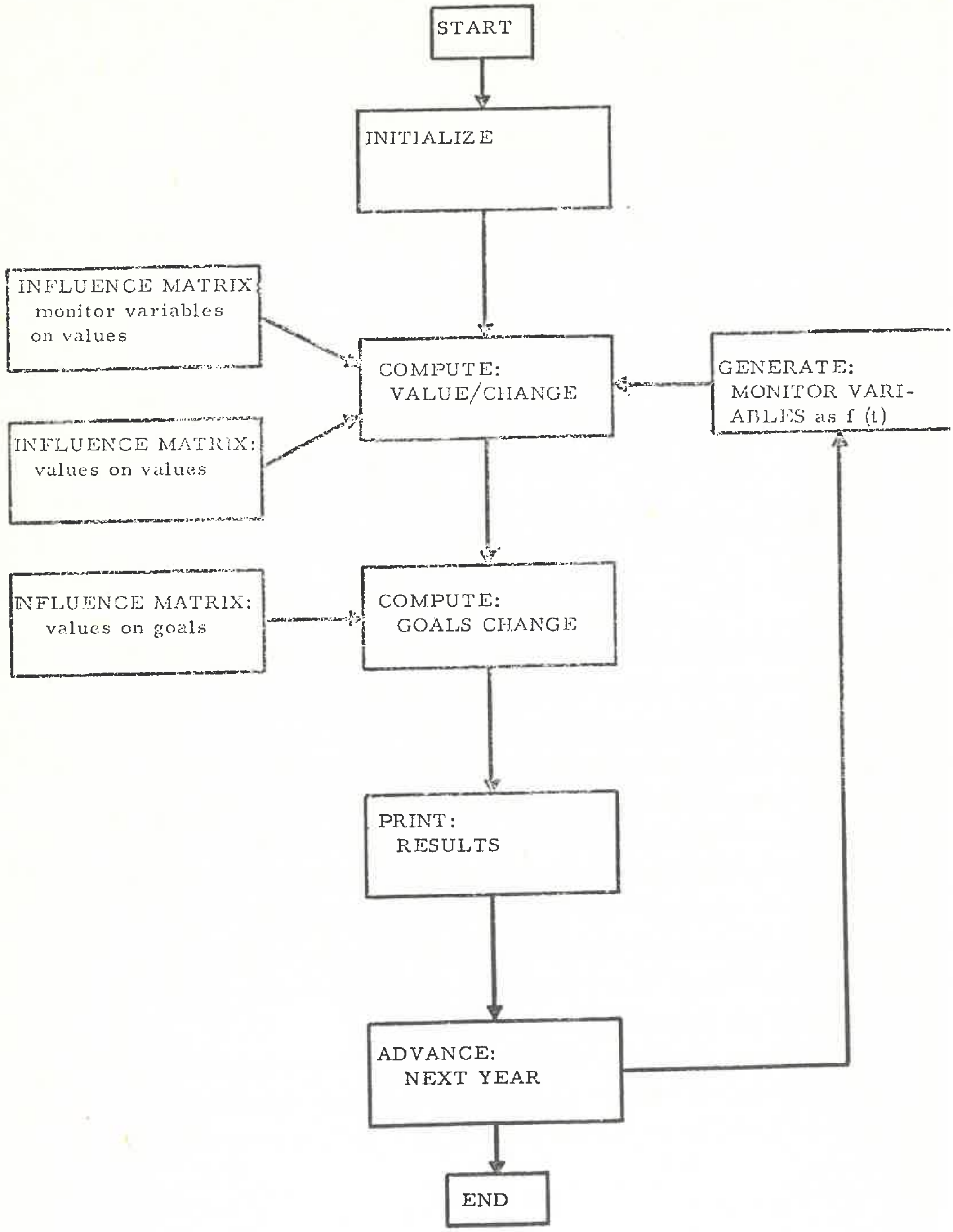


Fig. 4. 5 - Flow Chart of Norms Stratum Simulation Program.

for the goals are similarly computed via the influence coefficients u. At the end of a computational cycle, the new levels and rates of change are recorded. The output of the norms stratum subprogram to the calling decision stratum subprogram consists of the newly computed annual percentage rates of change for each of the goals. A more complete model of the norms stratum would also supply rates of change in the goal weights.

Test results

The present subprogram of the norms stratum is essentially self-contained and can easily be tested separately from the full decision simulation. The input consists of a timedependent scenario for the monitor variables, while the output gives the resulting value and goal changes. This mode of operation has been applied to check the consistency of individual assessments, and to generally compare the computed results with expectations. The results provided by the subprogram are felt to be quite reasonable, and the present model of the norms stratum is therefore used with confidence in the full simulation of the decision process.

Fig. 4.6 shows the computed value changes for each of nine scenarios. In each of the scenarios, only the monitor variable indicated was changed linearly from a value of " moderate" to a value of "high" in the space of five years. All other monitor variables remained constant at the value "moderate". The reader is invited to compare the results with his own assessment of the particular situation. Table 4.4 gives value and goals changes for the nine scenarios .

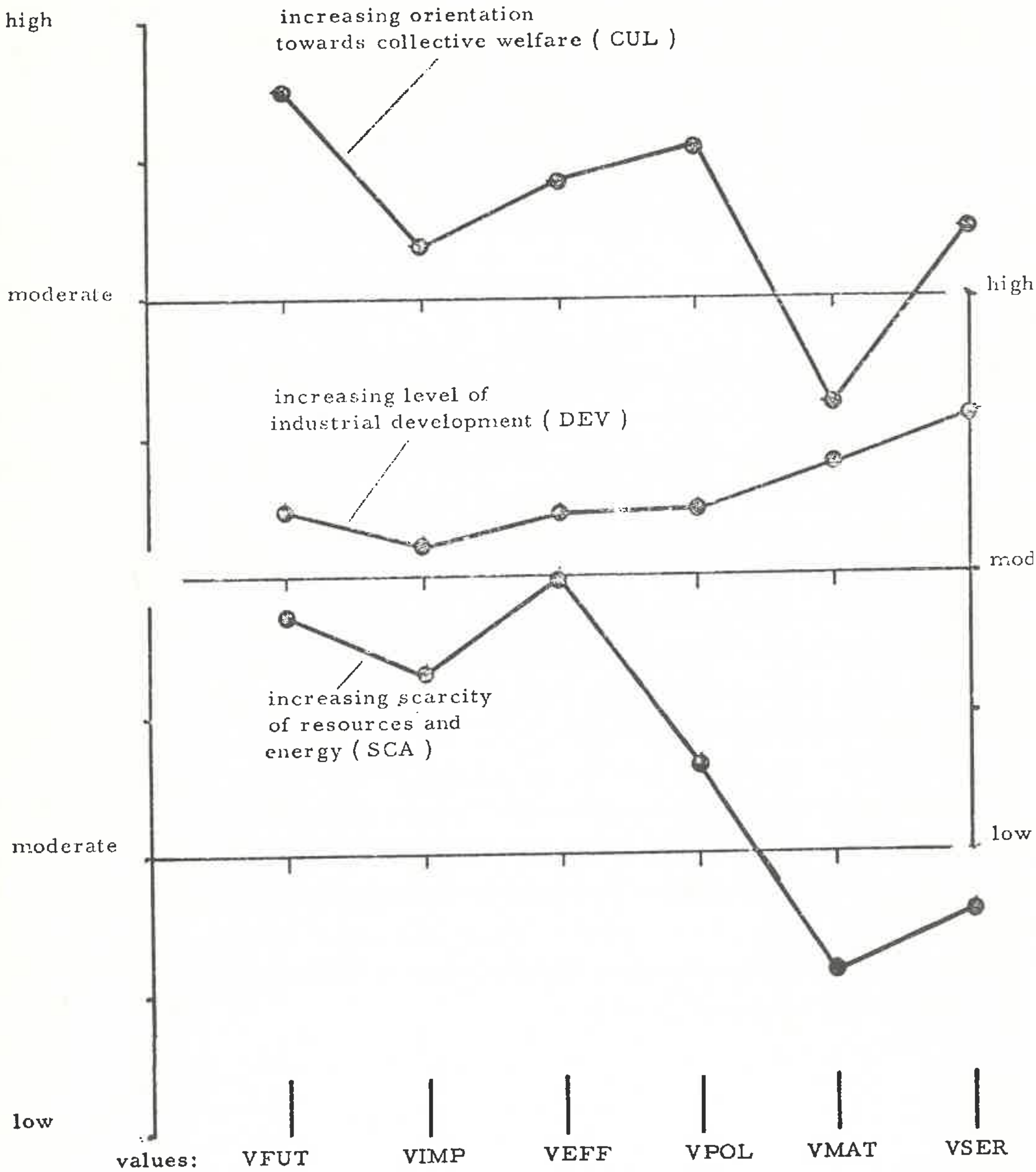


Fig. 4.6a - Computed Value Changes for Three of Nine Scenarios

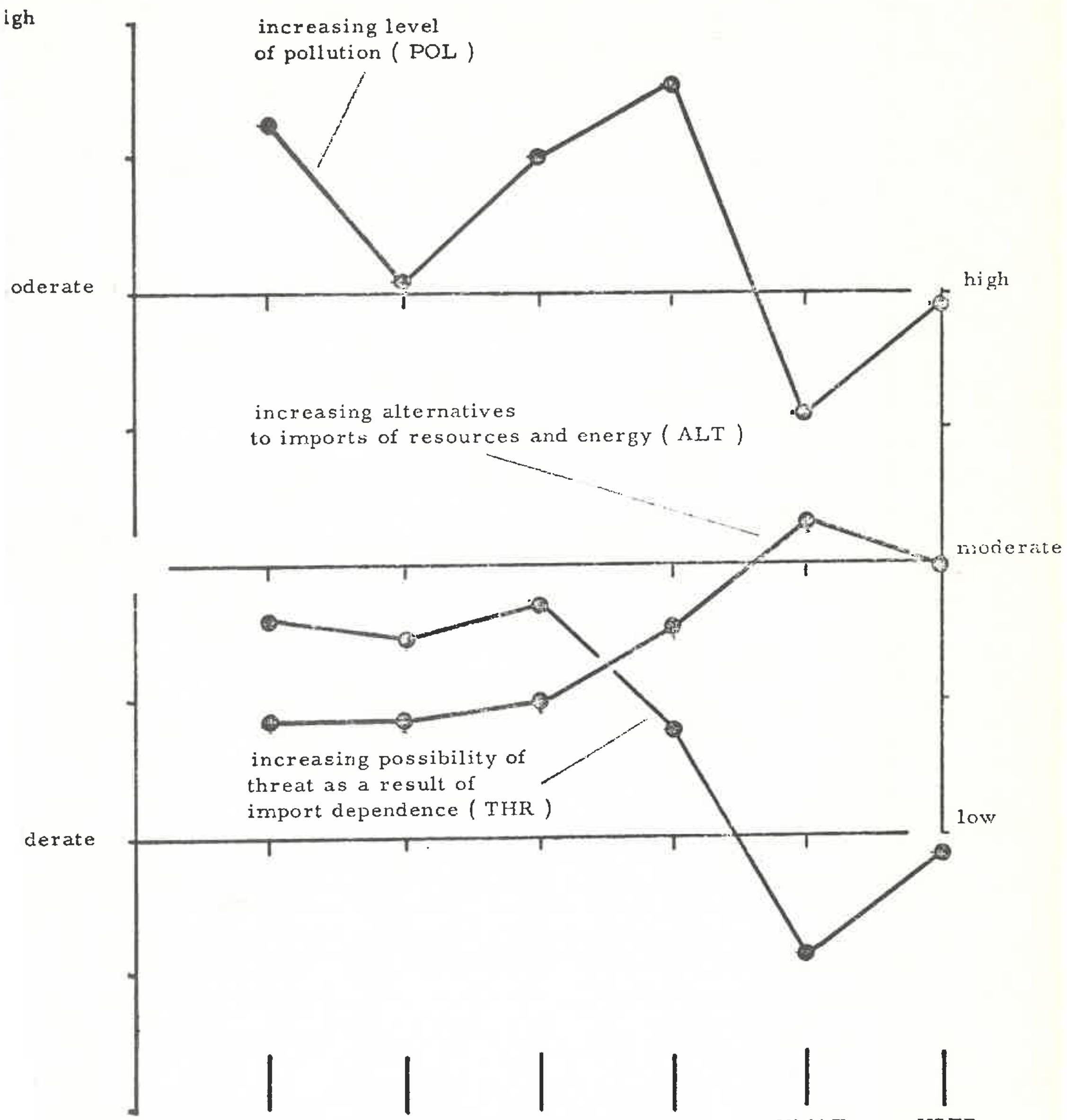


Fig. 4. 6b - Computed Value Changes for Three of Nine Scenarios

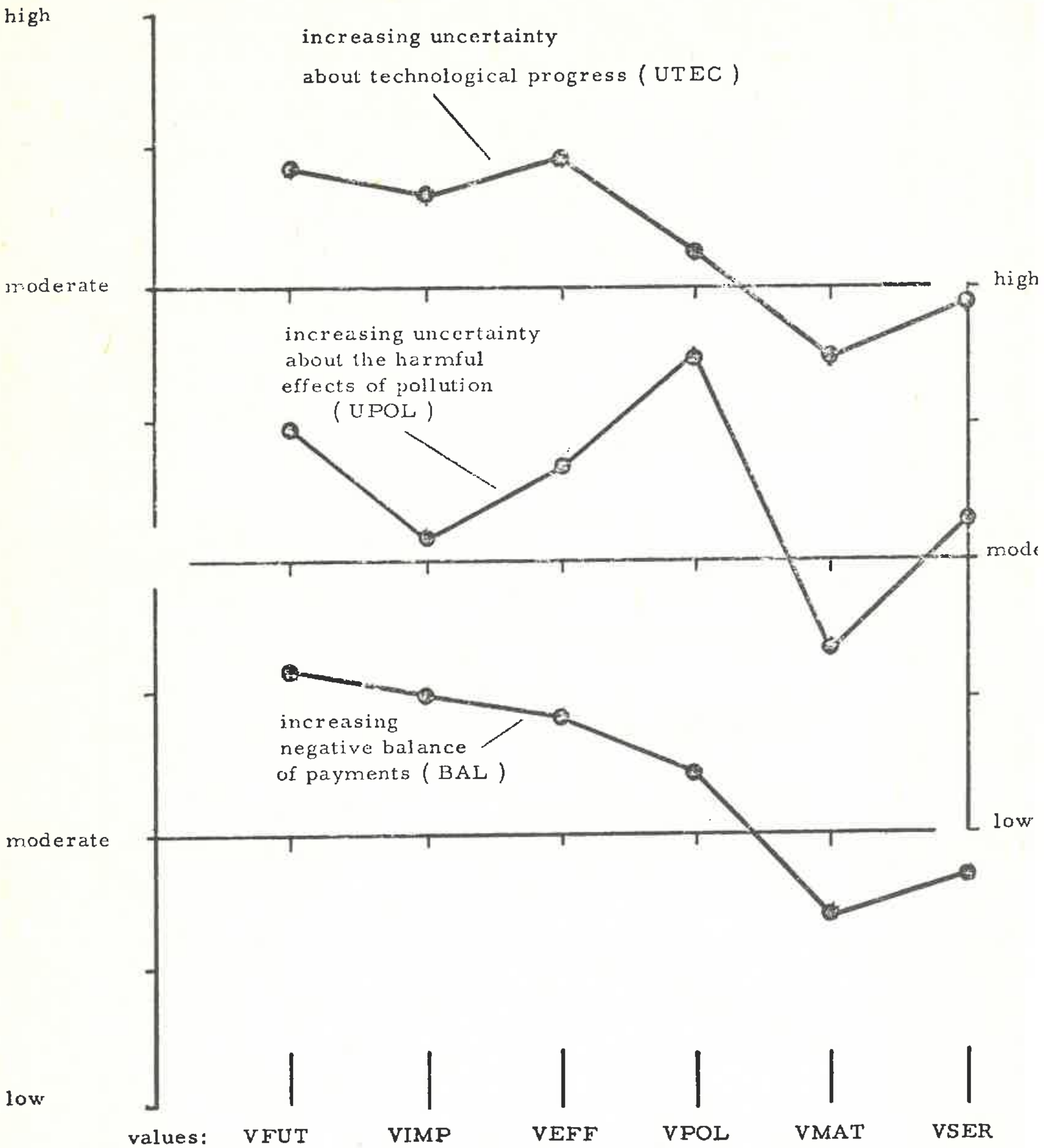


Fig. 4.6 c - Computed Value Changes for Three of Nine Sce narios

Table 4. 4 - Values and Goals following Different Scenarios

Scenario	Values [1]						Goals [2] (percent yearly change)				
	VFUT	VIMP	VEFF	VPOL	VMAT	VSER	GECPC	GIM	GYIPC	GYSPC	GGRP
(1) increasing orientation towards collective welfare (CUL)	.68 †	.54	.61	.64	.41	.57	-5	-5	-4	-7	-2
(2) increasing level of industrial development (DEV)	.57	.53	.56	.56	.60	.64	3	0	4	6	6
(3) increasing scarcity of resources and energy (SCA)	.72	.66	.75	.58	.39	.46	-11	-11	-5	1	-6
(4) increasing perceived level of pollution (POL)	.66	.51	.63	.70	.39	.49	-7	-5	-5	4	-4
(5) increasing alternatives to imports of resources and energy (ALT)	.37	.37	.38	.44	.54	.50	5	6	2	-1	2
(6) increasing possibility of threat as a result of import dependence (THR)	.70	.68	.72	.60	.39	.48	-10	-11	-4	2	-5
(7) increasing uncertainty about technological progress (UTEC)	.61	.58	.62	.53	.43	.48	-5	-6	-2	0	-3
(8) increasing uncertainty about the harmful effects of pollution (UPOL)	.63	.52	.59	.69	.42	.54	-5	-4	-3	6	-2
(9) increasing negative balance of payments (BAL)	.65	.65	.61	.57	.42	.46	-7	-8	-3	0	-4
	concern about the future	concern about dependence on imports	concern about efficiency of resource use	concern about harmful effects of pollution	expectations concerning material standard of living	expectations concerning service standard of living	goals for: energy consumption per cap.	energy imports	industrial output per cap.	service output per cap.	gross regional product

† - denotes increase

1 low= .25, moderate= .5, high= .75

2 before goal relaxation

Footnotes and References to Section 4

[1] M. Mesarovic, E. Pestel, et al., "An Interactive Decision Stratum for the Multilevel World Model," paper presented at the annual meeting of the Club of Rome, Paris, January 1973 (Systems Research Center, Case Western Reserve University, Cleveland, Ohio)

[2] see the discussion in Sec. 3.2

[3] Nicholas Rescher, "What Is Value Change? A Framework for Research", in K. Baier and N. Rescher, Values and the Future, Free Press, New York, 1969, p. 77

5. GOAL-CONTROLLED DECISION-MAKING STRUCTURE

5.1 Introduction

As has been noted above, the interface between the norms stratum submodel and the decision stratum is in goal setting by the norms stratum. These goals then perform a directive function for the decision stratum -- as would the goals of an interactor in the interactive mode.

The decision stratum has roughly the same basic components in the interactive and norm-simulated modes[1]. The basic elements in each process are:

1. Monitoring the crucial variables in the environment.
2. Establishment of a set of relevant policy options.
3. Search (es) within the set.
4. Evaluation of the search (es).
5. Policy choice once satisfaction is reached.

The manner in which these elements are structured for the interactive mode is described elsewhere [2]. Here we will focus on an approach for their structuring which allows effective interface with the norm-change submodel.

The overall objective of the decision stratum is to select a policy mix (not a single policy) which will reasonably well duplicate the kind of policy mix decision-makers would be most likely to select given the kinds of norms and goals provided to the stratum. It is possible, of course, to produce an "optimal" policy mix under these circumstances. This might be highly useful for a policy-maker who wished to specify his goals and have the model produce a potentially useful set of policies. But in many cases, such a policy mix would be quite "unrealistic" -- that is, it is not likely to be the kind of policy selected by a decision-maker in an environment with a shortage of knowledge, time, and other resources, and faced with many competing inerests. It is, of course, this kind of constraining environment which leads to the incremental and satisficing decisions well documented in decision-making literature [3]. On the whole it is these sub-optimal types of decision which we want the organizational stratum to produce. Since we are particularly concerned, however, with decision-making in the face of major problems or crises, the incrementalism element should not be overemphasized. In the face of major disruption in their environment, decision-makers resort to an approach which Etzioni calls "mixed scanning"[4]. That is, they search somewhat more widely for potential policies than an incremental model would suggest, and then examine in more depth the neighborhood of the most promising policy(ies).

5.2 Monitoring the environment

All decision-makers keep an eye on what they consider critical elements of their environment (through quantitative and qualitative means). This environmental monitoring process introduces norms or values because monitoring implies evaluation in terms of some desirable state of the environment or some goals. In this section we will first discuss the establishment and changing of goals, and then explain how these goals can be used to evaluate the environment.

Establishing and changing goals

Goals specify the performance level of key environmental variables below which decision-makers will be dissatisfied and will act to improve performance [5]. These goals will generally, but not invariably, exceed the actual performance of the system.

There are two issues connected with the individual goals -- the establishment of them and the changing of them. The establishment for the operation of the model can be done in two ways:

1. Interactively by a model user.
2. By us through observation of past decision-making behavior.

Both procedures have utility and although only the latter is used in the prototype developed for this report, it is also suggested that interactive establishment be allowed.

As a base for discussing the changing of goals it is useful to note that Cyert and March have outlined three factors which determine the levels of organizational goals [6]:

1. Previous goals.
2. Organizational experience with respect to goals of the recent past.
3. Experience of comparable organizations.

These should be supplemented by a fourth factor: external factors which cause a change in values of decision-makers in the organization and lead to alterations in goals. Cyert and March were probably relatively unconcerned about such goal changes because the organizations in which they were most interested, namely firms, hold maximization of profit quite consistently as the major value. Even firms, however, sometimes act to "improve their public image" or to "clean up the environment," and although there may be long-term profit motives, the introduction of other values and their impact on short-run goals would be useful in explaining such behavior. In the nation-state it is clear that many values must be considered and that these can change considerably over time and with changes in the environment.

This fourth factor determining goal level was the subject of the previous sections, and no more need be said about it here. Goal change as a function of organizational experience with respect to its past goals also plays a very important role in decision-making behavior, however, and we should turn our attention to it. We all recognize the phenomenon of changing organizational or individual expectations in the light of past achievements. At the individual level, for instance, a man who decides to put together a jig-saw puzzle one evening, but does not finish it until a week later will adjust his time goal for the next puzzle he attempts significantly upward. Similarly, if he finished it in two hours, his goal for the next one would be somewhere between two hours and a full evening. At the organizational level, a branch of the military which desires a 10% budgetary increase, requests 20% for tactical reasons, and receives 15%, will almost certainly set its goal closer to 15% for the next year. Or if it receives only 5%, it will adjust its goal downward, although probably not as significantly as the upward movement in the successful case. Students of revolution also stress this phenomenon of goal adjustment to reality. They have noted that major revolutions very seldom occur in a country when conditions are stable, even though conditions might seem abominable to the outside observer. Instead, revolutions most frequently occur when conditions have been steadily improving for some time (generating a steady upward movement of goals) and then fail to improve.

Thus the decision-making mechanism should and does incorporate a mechanism for automatic adjustment of goals to reality. If goals of the past time period have not been met, those goals are adjusted slightly downward (10% of the gap). Similarly, if goals have been exceeded by performance, goals are moved towards the performance level even more significantly (25% of the distance). The final source of goal setting and change noted by Cyert and March, the experience of comparable organizations, does not have a representation in this structure, because at the moment we are dealing with only one decision-maker. When the model is more fully regionalized, such a mechanism would be desirable.

Evaluation in terms of the goals

The establishment of a scale of evaluation is more complex than the establishment of a point goal. It is necessary, however, if we are to be able to simulate action designed to satisfy (at least partly) many values and goals. There are two basic procedures for dealing with multi-goals in a decision-making simulation. One is to develop a ranking or priority list of the goals and to develop a search procedure which first attempts to satisfy the top-ranked goal, then the second ranked, and so on down. The second is to develop a function of satisfaction - dissatisfaction which involves a simultaneous examination of all the goals, although weighting some less heavily than others.

The first approach is simpler than the second because it does not require the development of basically interval scales of the values and their satisfaction - dissatisfaction as does the simultaneous examination. This is probably why it appears in some discussions of decision-making. It is really quite unrealistic, however. Decision-makers do not examine policies on the basis of one goal at a time, trading satisfaction of the higher ranked ones for potentially major dissatisfaction of lower ranked ones. Decision-making is a balancing process involving an effort to partly satisfy all values, although clearly considering them of different importance. Moreover, any effort to plan involves balancing projected future satisfaction or dissatisfaction against the present -- this can not be done with a ranking system.

What is needed, then, are scales of dissatisfaction (or satisfaction) which allow joint consideration of several goals (of varying importance or weight) over a time horizon extending several years into the future.

Joint consideration can be accomplished with a function like this measure of total dissatisfaction:

$$\frac{\sum_{i}^{goals} \sum_{j}^{time} a_i b_j \left[\frac{(goal_i - projected_i)}{goal_i} \times 100. \right]^2}{\sum_i \sum_j a_i b_j}$$

a_i = weight by goal

b_j = weight by year

Basically this function computes the gaps between the goal for a variable (say GNP growth) and present and projected values for that variable, normalizes these gaps by the size of the goal, and weights them according to the importance of the goal and the time period. If any goal is exceeded in a particular time period, there is no dissatisfaction and that element of the sum is set to zero. The squaring stresses the importance of extreme values of dissatisfaction -- that is, the difference between 30% and 35% dissatisfaction should be more important than that between 0% and 5%. The multiplication by 100 before the squaring merely eliminates decimal values. The division by the sum of the weights normalizes the entire dissatisfaction function. Thus a value for the function of 10 indicates an average dissatisfaction over all the goals and for all years considered of about 3%. For instance if the goal for GNP growth were 3.5% and the actual value were about 3.4%, the dissatisfaction would be roughly 3%. A value of 100 indicates an average of about 10% dissatisfaction (say 3.15% GNP growth versus a goal of 3.5%) and a value of 1000 indicates 33% dissatisfaction. Because we are interested in major problem situations we will be most interested in problems within the 100 - 1000 dissatisfaction range.

The weights for the goals and the years deserve discussion. One way of treating these is again interactively. For instance, a user might wish to emphasize future planning and he would provide weights which stressed a 5 year, 10 year, or even longer horizon. For the simulation of more realistic decision-making a weight of 1 for the coming year, 1/2 for the second year, and 1/2 more for the fith year might well represent most national decision-makers. Of course, these weights should be region-dependent.

The weights for the various goals are probably more important since the dissatisfaction function is more sensitive to changes in them (changes in year weights are important only if the variables are performing erratically or changing performance substantially). These weights can also, of course, be determined interactively. The possibility of determining them from the values was discussed earlier. A major problem is the lack of independence among goals. For instance, the rate of growth of energy consumption is directly dependent on the rate of growth of GNP. Thus if both are considered in the dissatisfaction function it is in reality a double weighting of GNP. Of course this same "weighting" problem occurs for a decision-maker. We will simply need to proceed carefully and to research the decision-making in the issue area.

The evaluation function is, of course, not just important in the initial monitoring of the environment (and decision as to whether action is necessary), but also in evaluating the projected consequences of any action. We shall return to the search procedure and evaluation later. We should briefly first consider the second basic element of the organizational stratum, the establishment of a set of relevant policy options.

5.3 Policy options

The policies available to the decision-maker, or his access points to the environment, will depend directly upon that environment. For instance, we will discuss some specific policies for the decision-makers in the energy issue area while presenting the prototype model in the next section.

One of the major issues which we will face in the future of the modeling efforts is the generality of the policy option set. Decision-making theorists stress the factored nature of decisions[7]. That is, decision-makers are generally concerned only with a relatively narrow issue area, even when that issue area is importantly tied to other issue areas in the environment. A good example of this has been the separation between environmental policy and energy policy -- many decisions in each area have adversely affected the other area.

Thus a "realistic" treatment of decision-making would call for such separation of action boundaries. Yet an approach emphasizing search for solutions to major world problems cannot afford such irrationality. Thus we will need to develop flexible policy option sets -- smaller and more specifically issue-oriented for the more realistic norms-simulated mode, and larger for the policy analysis interactive model. In the development of the prototype model for the energy issue area, there was no attempt to develop policy options, such as population policy, which do affect the attainment of goals, but which are more general than those options usually considered by energy policy makers.

5.4 Policy search

As noted earlier, when significant environmental problems exist, decision-makers are likely to operate under a procedure of mixed-scanning decision-making. They are likely to look more widely initially within their policy set than suggested by incremental theory, and then examine in more detail the neighborhood of the most fruitful alternatives.

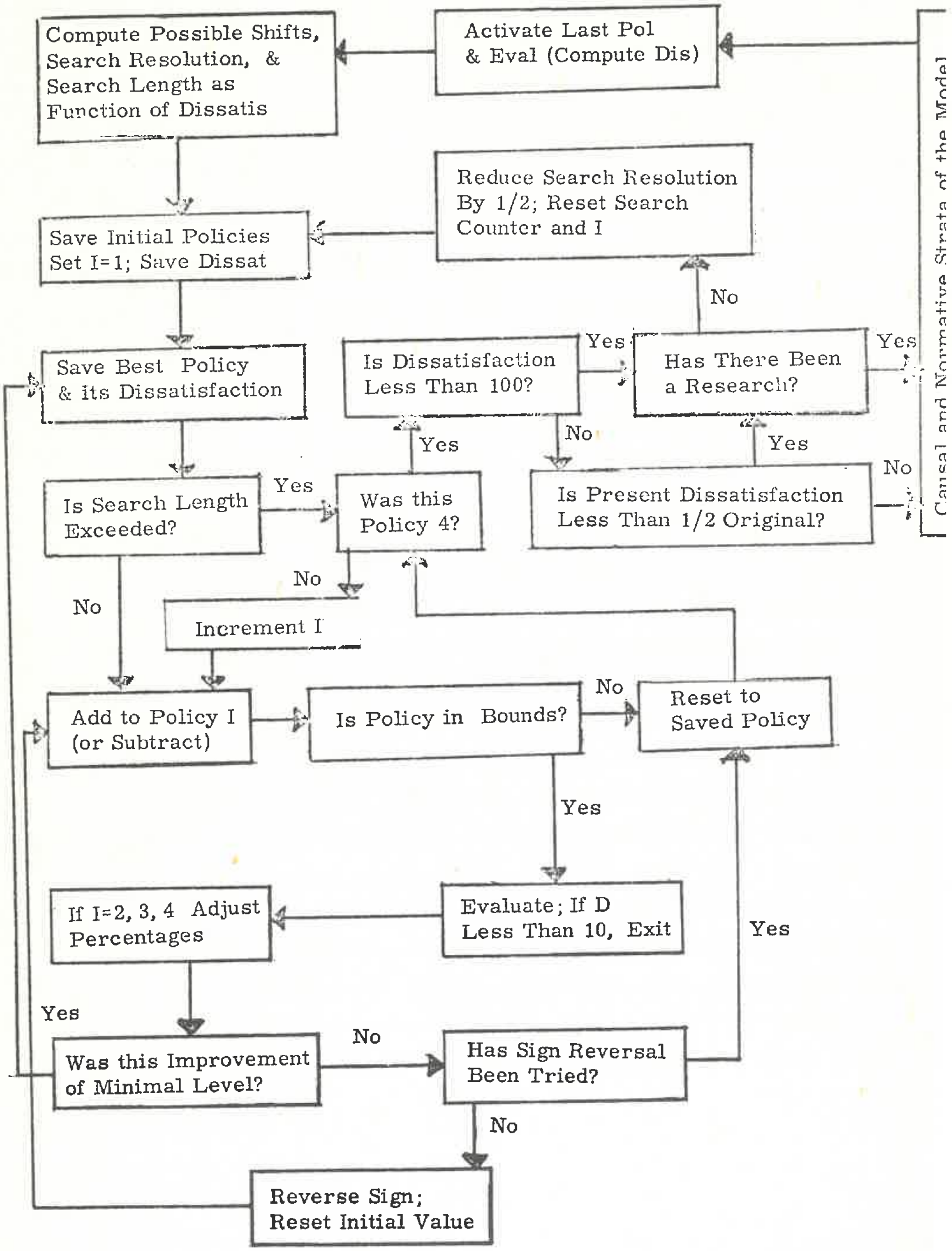
This general conceptualization of decision-making has led us to the search pattern portrayed in Figure 5.1 .

The search begins with a consideration of last year's policy and its projected consequences. This consideration involves applying the evaluation function described above to projections for the future given a continuation of action [8]. The reasons for selecting the policy applied in the past as a starting point for the policy search should be obvious. To begin with it allows us to decide if a re-evaluation of action is needed at all, or if the past policy is adequate. And if a search is needed for a new policy, even in a mixed scanning procedure the most likely decisions are in the neighborhood of past policy.

On the basis of evaluation of last year's policy, both the length of the search and the resolution of that search are determined. If the dissatisfaction with last year's policy is large, the decision-maker will search more widely for new policies (the resolution will not be as fine) and the search will proceed for a longer period of time.

The procedure for the search is to experiment with increases and decreases in each policy, continuing the experiments until either they do not improve the dissatisfaction value or the outer limits of the search are reached. If at the end of the first search efforts satisfaction (to be discussed below) has not been obtained, the search resolution is reduced and the search continues in the neighborhood of the best alternative discovered in the wider search. It would be possible to develop some algorith ms to direct the search given the types of goals which have not been satisfied. Such a procedure would be more "realistic" than this basically undirected outward search pattern. Yet both types of search (assuming that the algorithms were good ones and did not lead the model astray) would be likely to arrive at similar policies.

Figure 5.1 - The Flow of Decision-Making.



5.5 Evaluation during the search

All decision-making is based on some type of cost-benefit calculus, although at times the costs or benefits are very intangible. For instance, there is benefit in avoiding uncertainty, and this is a major factor in the calculus that leads to largely *status quo* or incremental decisions. It is thus reasonable to ask whether costs and benefits are generally accurately represented in this approach.

It is possible to talk about two sources of costs and benefits in the decision-making process. The first is within the decision-making organization itself. Analyses repeatedly show that organizations perceive that primarily costs are involved in change, and that most of the benefits result from the *status quo*. Organizations contain subdivisions which exist because of the *status quo* and wish to protect that existence. Benefits of change might be growth and some of its rewards; costs may be loss of jobs. Uncertainty surrounds change and the general tendency is to avoid it. These principles are built into the model through the search procedure, with its origin at old policies and its restricted scope. They have been somewhat de-emphasized because in the face of major problems organizations are able to break out of old patterns.

A major reason that organizations are able to adapt in such situations is that costs and benefits from their environment become more relevant than internal organizational ones. In the case of nation-states, the most relevant aspects of the environment are the groups which channel demands and supports to the government. These groups react in a complex way to *their* environment (the physical processes represented in the lower layers of Figure 2.1). They both pressure the government to adopt policies to changing conditions in order to satisfy ongoing values, and they pressure the government to adopt policies to values altered by changing environmental conditions.

The approach being suggested here does represent these pressures. On the one hand, changing environmental conditions affect values which in turn affect goals and action. On the other, the same and other changing environmental conditions also cause the decision-making structure described above to try to adapt to satisfy ongoing goals. These mechanisms do not explicitly simulate political pressures, but they do represent the net affect of them.

On the whole, the simulation approach laid out in this report goes considerably further in the inclusion of the full range of costs and benefits affecting decisions than any other simulation of which we are aware. The major cost or benefit not discussed to this point are instrument costs. Most government action does involve some monetary or other instrument costs, but we should be careful not to overestimate these costs. Most government action involves a shifting of monies from one group to another. This can be construed as a monetary instrument cost, for instance when new taxes must be raised, but the really important costs are involved in the dissatisfaction raised in the group from which the money was raised. In many cases, this will already be represented in the approach suggested here by the inclusion of goals for the disadvantaged group (e. g. a sector of the economy) in the evaluation equation.

To use a concrete example, in the energy policy area the shifting of investment to energy production from other areas of the economy disadvantage those areas. But in the prototype model to be discussed below, goals for growth for the other sectors of the economy as well as for the energy sector are included in the evaluation equation. Thus if the transfer of monies has a negative impact on one of the sectors of origin, it will show up as a cost; if the transfer has little impact, the cost would be low. There is, of course, a residual aspect of instrument costs, namely the additional bureaucracy and the additional work for it required by all action. This, however, should have small weight in the overall cost-benefit calculation. We have tried to represent it by adding a small factor to the evaluation equation which does incorporate such costs as a function of the magnitude of the action.

5.6 Policy choice

Although the policy search and alternative evaluation has been discussed above, the criteria for the final choice have not been. Clearly, the alternative with the lowest total dissatisfaction associated with it will be chosen. The problem is when to cease the search for a better alternative.

Since this is a satisficing and not an optimization approach, the search will not continue until the "best" alternative is found. This would overestimate the precision of the measures as well as misrepresent the behavior of decision-makers. Instead, the search will continue until a satisfactory alternative is uncovered -- one of potentially many similarly satisfactory alternatives.

Satisfaction is a function of at least three things. First, satisfaction depends an the remaining dissatisfaction in the evaluation function. For instance, if that drops below 10 (an average of 3% dissatisfaction) the search should certainly end. Satisfaction is also dependent on the relationship between the projected impact of the alternative considered and the alternative of no change in the old policy. For instance, if the average dissatisfaction with the alternative considered falls to a fraction of that of the original policy the search may well be ended (unless dissatisfaction is still very large). Yet a third factor determining satisfaction is the improvement to effort ratio. If the search results in very significant reduction of dissatisfaction with moderate effort, the search may go on, while little reduction in dissatisfaction may cause the search to be given up.

These notions of satisfaction are built into the prototype program. If the dissatisfaction falls below 10, the search ends immediately. If after trying changes of all policies dissatisfaction falls below 100, the search is ended (unless the search has resulted in reduction of dis-satisfaction by 1/2, in which case the search procedes). If there is a search after all policies have been changed initially, it is with an increased resolution around the neighborhood of the most promising policy. Many other algorithms for the search and the final choice could be developed, but the model is not too sensitive to exact procedures.

Footnotes and References to Section 5

[1] The general structure of the decision-making process is discussed in Barry Hughes, "Regionalization and Decision-Making in a World Model," Systems Research Center, Case Western Reserve University, August, 1972, mimeo.

[2] M. Mesarovic, E. Pestel, et. al., "An Interactive Decision Stratum for the Multilevel World Model," paper presented at the annual meeting of the Club of Rome, Paris, January, 1973.

[3] See especially Charles E. Lindblom, "The Science of Muddling Through," Public Administrative Review, Vol. XIX, No. 2 (Spring 1959), pp. 79-88, James March and Herbert Simon, Organizations (New York: Wiley, 1958).

[4] Amitai Etzioni, The Active Society (New York: Free Press, 1968).

[5] In earlier discussion of decision-making this was called the "crisis level", although it was noted that the dichotomy between crisis and non-crisis situations was not a relative one.

[6] R. M. Cyert and J. G. March, A Behavioral Theory of the Firm (Englewood Cliffs: Prentice-Hall, 1963), p. 123.

[7] Graham T. Allison, "Conceptual Models and the Cuban Missile Crisis," American Political Science Review, Vol. LXIII, No. 3 (September, 1969), pp. 698-718.

[8] These projections and the cognitive map which generates them have been discussed in Hughes, op. cit. Rather than create a cognitive map for the decision-maker we are now using the causal stratum to generate projections for him. This may in many cases be a considerably more sophisticated cognitive map than decision-makers actually possess.

6. PROTOTYPE MODEL: OPERATION AND RESULTS

6.1 Introduction

In order to illustrate both the importance and effectiveness of the general approach described above, a fully simulated decision-maker with decision stratum and norms stratum was developed to make decisions on energy policy in the developed world. This region and issue area were chosen because of the prior development in the M-P World Model Project of an interactive decision-maker for developed world energy problems. Fig. 6.1 illustrates the flow of the entire program, and shows the couplings between norms, decision-making, and environment.

The environmental base of the M-P interactive model, including the original four sector economic model and the rudimentary production and consumption generating energy model were taken without change. Similarly, the policy options of the interactive model were adopted. The most important of these is the transfer of capital from other sectors of the economy into energy production. Because the model is structured to always meet energy demand through imports and production, the policy of increasing or decreasing imports is implicit in that of increasing or decreasing investment in production. Decisions can also be made about the source of any investment transferred into energy; it can come from either the industrial or services sector. Because most analyses see considerable additional investment as necessary to meet energy demand without major import increases, the search procedure was initialized at a $ 7 billion transfer into energy with 50% coming from the industrial sector of the economy, 40% from services, and 10% from final consumption.

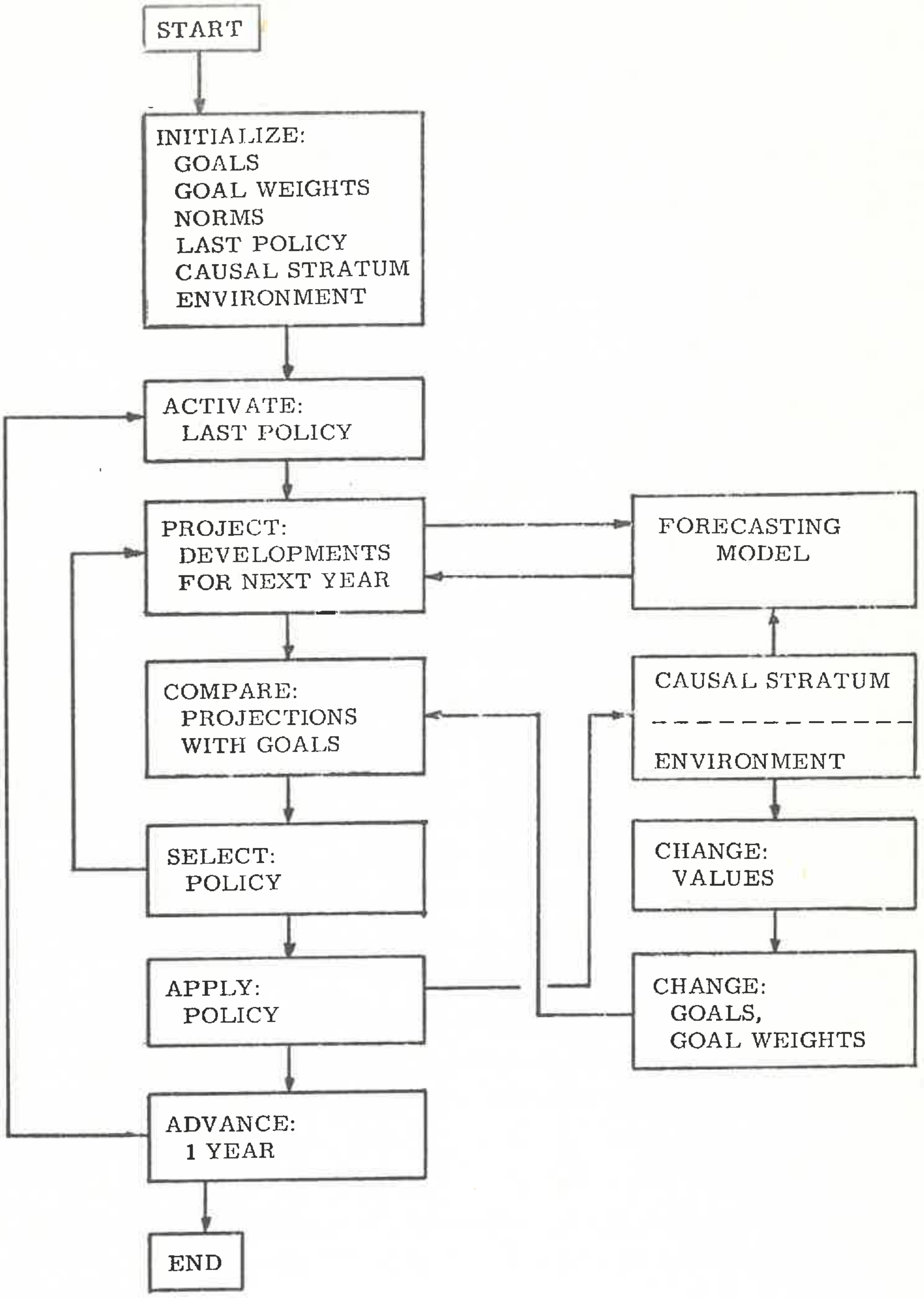


Fig 6.1 - GOAL-ADAPTIVE DECISION PROCESS

6.2 An example decision-maker search

Table 6.1 shows an example search pattern, in which the decisions being made are how much investment to transfer into energy (in billions of dollars) and where to obtain the money for that investment (from industrial sector, from the services sector, or from general consumption). This is the kind of search which occurs every year in the model, once the goals for the year have been established. The search begins with the policy applied the previous year. It then tries increasing and decreasing each possibility in turn. Only with the case of increasing the proportion of the money taken from general consumption (and decreasing it from elsewhere) was it successful. After it failed to achieve further success with this policy, dissatisfaction was still quite high (445). It thus increased the resolution of the search and searched further in the neighborhood of the most successful policy. Since no policy was found which reduced the dissatisfaction by at least 1 full point, the final policy applied was the one which proved most successful in the first search.

This illustrates the working of the search and evaluation procedures. These procedures are really meaningful, however, only in the context of the goals set for the decision-maker and their weights. It is theoretically possible to set goals for the performance of any variable in the model. The most obvious ones are energy production, consumption, and imports, and the performance of the economy, especially the industrial and services sectors. As noted above, production and imports are completely complementary, however, so it is only really necessary to focus on one. Similarly, the overall performance of the economy as measured by the gross regional product, reflects very closely the performance of the industrial and services sectors. Moreover, energy consumption is computed as a function of the size of the economy. There are thus two

Table 6. 1 - An Example Search of the Decision-Maker

Investment into Energy (AKTM)	% from Industry (X1)	% from Services (X2)	% from Consumption (X3)	Dissat	Action Taken
4. 71	50. 00	40. 00	10. 00	452. 97	Original
6. 97	50. 00	40. 00	10. 00	492. 96	AKTM up
2. 44	50. 00	40. 00	10. 00	525. 92	AKTM down
4. 71	54. 52	36. 37	9. 09	454. 66	X1 up
4. 71	45. 47	43. 62	10. 90	453. 56	X1 down
4. 71	46. 22	44. 52	9. 24	454. 48	X2 up
4. 71	53. 77	35. 47	10. 75	453. 62	X2 down
4. 71	47. 48	37. 98	14. 52	451. 27	X3 up
4. 71	44. 96	35. 97	19. 05	449. 70	X3 up again
4. 71	42. 45	33. 96	23. 58	448. 23	X3 up again
4. 71	39. 93	31. 94	28. 11	446. 88	X3 up again
4. 71	37. 41	29. 93	32. 64	445. 66	X3 up again
4. 71	34. 90	27. 92	37. 17	444. 55	X3 up again
4. 71	32. 38	25. 90	41. 70	519. 57	X3 up again
		Search Resolution Reduced			
5. 84	34. 90	27. 92	37. 17	455. 44	AKTM up
3. 57	34. 90	27. 92	37. 17	522. 38	AKTM down
4. 71	37. 16	26. 94	35. 88	444. 47	X1 up
4. 71	32. 63	28. 89	38. 47	521. 06	X1 down
4. 71	33. 80	30. 18	36. 01	521. 87	X2 up
4. 71	35. 99	25. 65	38. 34	443. 81	X2 down
4. 71	33. 64	26. 91	39. 44	520. 23	X3 up
4. 71	36. 15	28. 92	34. 91	445. 10	X3 down
		Search Ended			
4. 71	34. 90	27. 92	37. 17	444. 55	Final Policy

clusters of variables in the model: energy production and imports, and economic variables. Although with weighting these provide a myriad of possible goal sets, we focused on one simple set. Specifically we weighted imports 1 (and thus implicitly weighted production also), and weighted production of the services and industrial sectors of the economy each 1 (and thus implicitly weighted the total economic performance and energy consumption). We thus suggest that decision-making for this original simple energy sector is essentially an exercise in striking a balance between the desire to increase production and thus limit imports, and the desire to avoid damage to the economy caused by capital shift to energy. We decided that for most decision-makers the latter goal would be most important. The initial values for the goals were set just slightly higher than actual performance in the first year. For industrial sector growth this meant 2.5%, in the services sector the goal was set at 2.7% growth, and the import goal was set at 40% of total consumption needs.

This selection of goals and their weighting will be different with future versions of the economic and energy models. For instance, energy imports are largely important in the overall context of the balance of payments, and if a measure of that balance were available, it should become the base of an import-oriented goal. Similarly, if energy consumption were not a direct reflection of GNP, but instead were determined by energy prices and other factors, it would be an important variable to include in the goal set.

6.3 Two basic goal-controlled runs

In order to show the operation of the goals, two runs of the model were made without the norm change procedures (although the automatic goal adjustment procedure for realignment of goals to reality was included).

The first run was made with no alteration to the basic economic and energy models. In the second run the costs of producing energy were allowed to increase at a rate of 5% per year. The results of these two runs are summarized in Table 6.2 . The table shows the shift in investment selected by the decision-making routine, the residual import level as a percentage of total energy consumption, and the total dissatisfaction level given the action.

Perhaps the most surprising aspect of Table 6.2 is that both situations led to a transfer of money out of the energy production sector. The reason for this lies in the economic model. That model produces a steady decrease in the growth rates of the economy from 1970 to 1980. Specifically, the growth rate in GRP dropped from 3.4% to less than 2.5%. Given goals which required a maintainance of economic growth as well as an effort to hold down imports, and a weighting of the economic goals as twice as important as the import goals, the decision-maker did the rational thing -- it shifted money out of energy production. In the second case, where energy production costs were climbing steadily, the transfer of money out was not as great, because it became even more difficult to prevent major increases in imports.

Note that in both cases the decision-maker remained stable. By the end of the 11 year period in the first case, dissatisfaction was actually slightly lower than in the first year, in spite of the steadily decreasing economic growth rates. Even in the second case, with the additional shock to the system of increasing costs of production, the decision-maker continues operating in an as effective manner as possible. In part this is because of the automatic adjustment of goals towards reality.

The result of these two runs, with a large scale shift of investment away from energy was quite different from the outcome of the interactive

Table 6.2 - Two Basic Goal-Controlled Runs without Norms Change

	Investment Shift	Imports	Dissatisfaction	Investment Shift	Imports	Dissatisfaction
1970	5.38	38.3	174	7.00	41.0	53
1971	6.74	36.8	235	6.42	42.5	113
1972	5.04	35.5	300	6.42	43.9	206
1973	3.11	34.5	354	5.22	45.6	232
1974	0.81	33.9	422	2.04	47.5	393
1975	-1.68	33.5	485	-1.70	49.9	477
1976	-6.58	33.8	322	-4.20	52.3	581
1977	-11.58	34.6	324	-6.33	54.7	417
1978	-16.43	35.8	241	-11.33	57.4	573
1979	-19.93	37.2	224	-16.33	60.2	490
1980	-19.93	38.4	170	-16.33	62.7	334

runs on the same model in which users invariably shifted capital into energy production. There are a number of possible reasons for this. It may well be that the interactive users did not realize that the economic model's growth rate was slowing down, since economic data were reported to them only in absolute and not percentage change terms. It may also be that the users focused largely on the energy data and not on the economic data because the model was called an "energy model". At any rate, the utility of completely specifying goals and their relative importance can be seen in the significant differences between these computerized runs and the typical interactive ones.

It may be, of course, that another reason for differences between these completely simulated runs and the interactive ones was that the interactors consciously acted with certain assumptions about changing values and changing environmental conditions over the next decade. For instance, a perception of increasing danger of an oil cut-off by the OPEC countries would lead to greater stress on maintaining low imports. On the other hand, increasing concern with pollution might result in some increased willingness to accept imports to avoid domestic environmental damage. We can now attach the norms change model to look at the likely impact of such factors.

6.4 Three cases with value change

Specifically, we can look at the impact of changing three environmental variables over the 10 year period, from values of "moderate" to "high". We will look at the impact of increasing perception of the possibility of an export cut-off or restrictions by the Arab nations, at the perception of increasing pollution, and an increasing scarcity of resources and energy supplies. In each case we will also incorporate the reasonable assumption that energy production costs will increase about 5% a year over the decade.

Fig. 6.2 and 6.3 summarize the decisions made in the three cases concerning investment shift into or out of energy production and the resulting level of energy imports. The case of perception of threat is perhaps most interesting because it leads to increases in investment in energy production as dramatic as the decreases in the two cases without norms. This is in large part because the threat leads to a 22% reduction in the goal for imports. It also leads, however, to some relaxation in the expectations for growth in the rest of the economy and this contributes further to the decision to invest in energy. On the whole the result seems quite reasonable. The case of increasing threat can be contrasted with the case of increasing pollution. There the decisions involve the transfer of investment out of energy production. Increasing concern with pollution leads, as might be expected, to a slight reduction in concern with imports. The more major effects, however, are to relax the goals for economic growth. In the case of GNP, the goal is reduced 10% (from 3.5% to 3.15%) as a result of the major perceived increase in pollution. The final case is that in which scarcity of energy and resources is increased from a moderate to a high value. The net result of this case is to maintain a low level of investment into energy production. The major reason is that scarcity leads to a fear of dependence on the outside and thus a reduction of the import goals. It also relaxes expectations concerning economic growth even more than does the perception of increased pollution.

Fig. 6.2 shows the actual impact on imports which the three policies have. Not even in the case of nearly $ 20 billion annual investment in energy by 1980 (that of perceived threat of cut-offs) can imports be maintained at the 41% initial rate. Instead they climb to 53%. At the other extreme in which $ 7.6 billion is taken out,

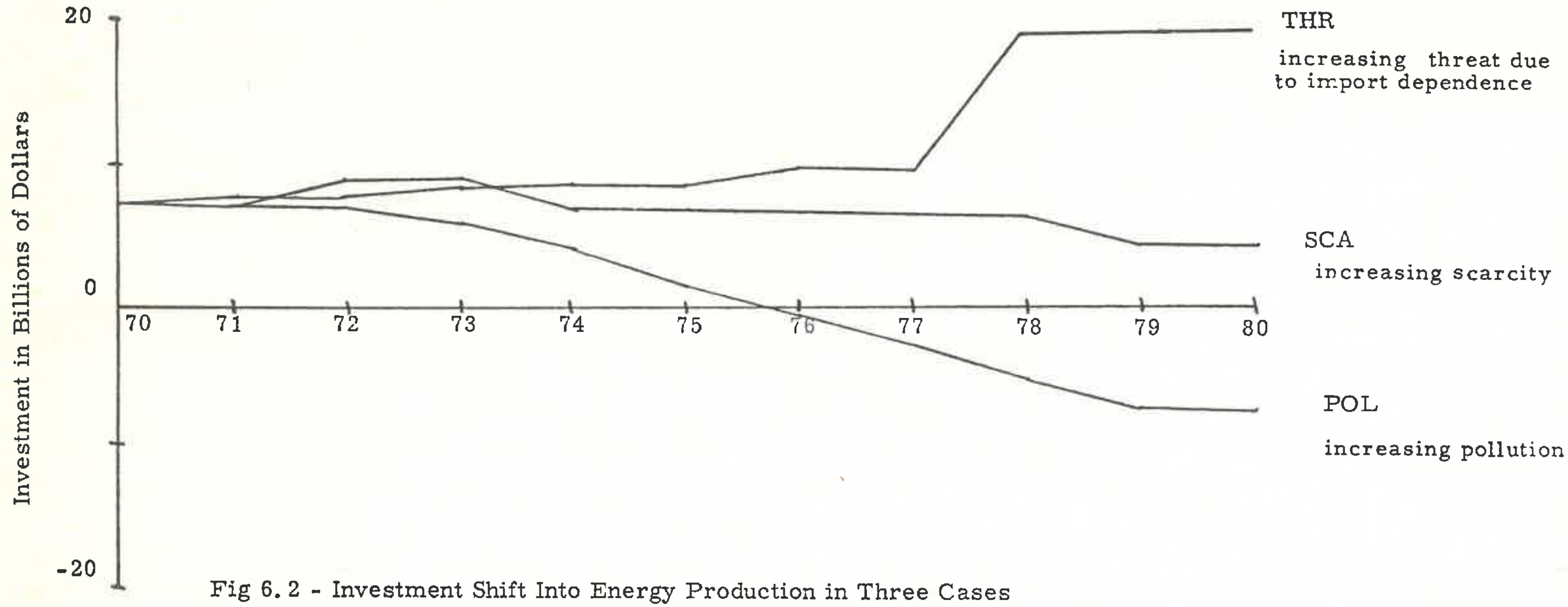


Fig 6. 2 - Investment Shift Into Energy Production in Three Cases

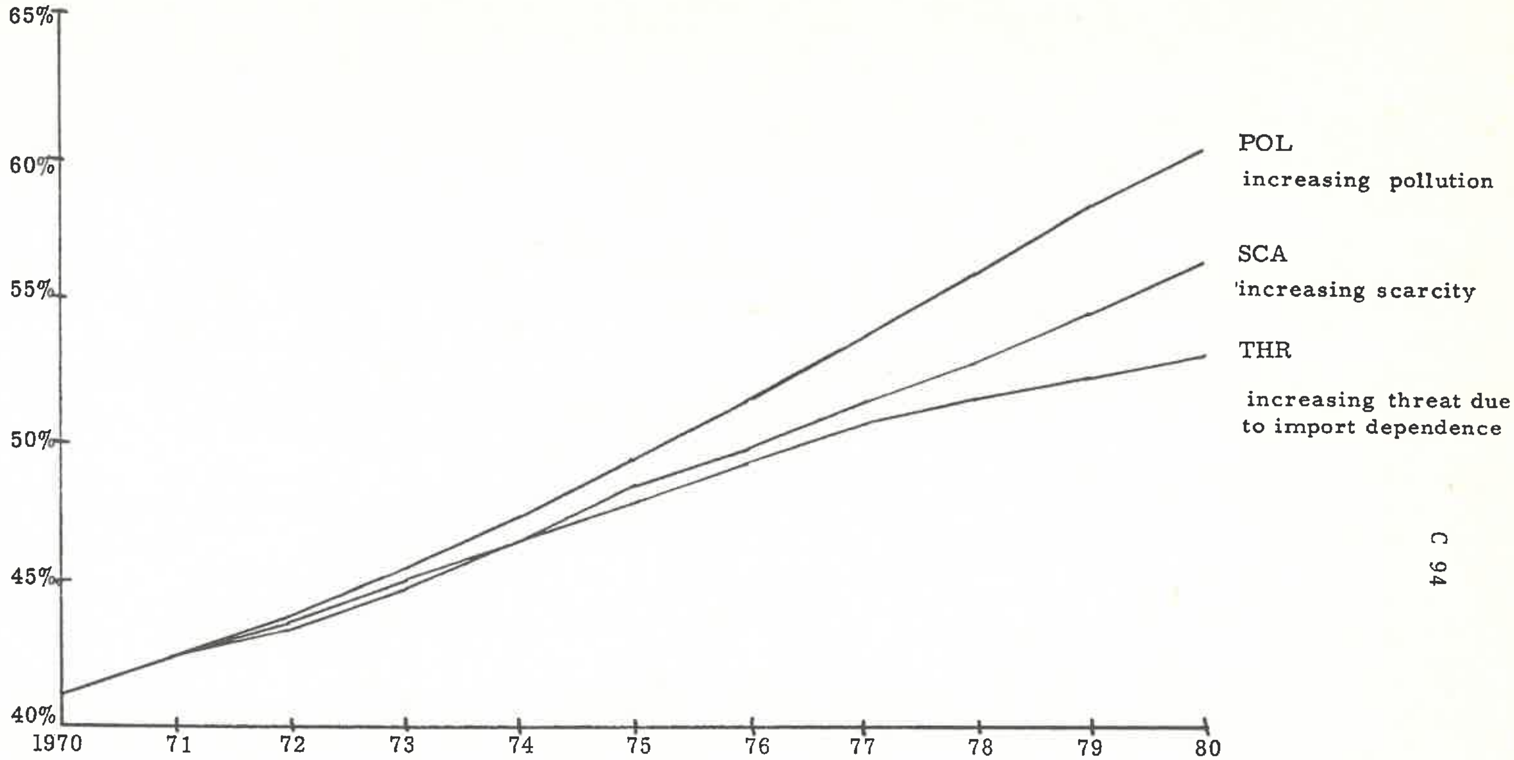


Fig 6. 3 - Imports of Energy as a Percentage of Total Consumption in Three Cases

imports rise to 60%. The difference is not actually that great, suggesting that even massive amounts of money cannot prevent import increases if costs increase by 5% a year.

6.5 Three scenarios for energy policy

Although all of these cases produce reasonable results, it is clear that the environment of energy policy is much more complex, with many changing variables. In order to show how the model reacts to more complex situations, we have created three more general scenarios for major variables in the energy environment over the next decade.

The first scenario can be called the "worst case". This involves postulating not only that energy costs will nearly double over the next 10 years, but that significant scarcities of energy and other resources will develop, pollution will increase from an average to a high level, the threat of an import cut-off will increase, and balance of payments problems will increase. A summary of this scenario and the other two can be found in Table 6.3. The effect of all these adversities of the "worst case" is to dramatically decrease the goal for imports -- it drops by 47%, making it necessary to try to significantly increase production through new investment. A summary of investment and imports can be seen in Figures 6.4 and 6.5. The conditions also have a depressing affect on other goals, however, so that dissatisfaction with the policy of investment is not as great as it might be. Nevertheless, this set of conditions poses a severe crisis for the system, and dissatisfaction rises at one point to over 1000 (an average of 33% difference between reality and each goal).

In contrast to this case, we have also tested a "best possible" scenario. This situation posits a small decrease in both scarcity and pollution, an increase in the alternatives to imports of energy (other

Table 6. 3 - Three Scenarios for the Energy Environment

Variable	Worst	Most likely	Best
CUL	Moderate (. 5)	Moderate (. 5)	Moderate–High (. 625)
DEV	Moderate–High (. 625)	Moderate–Plus (. 55)	Moderate–High (. 625)
SCA	High (. 75)	Moderate–High (. 625)	Low-Moderate (. 375)
POL	High (. 75)	Moderate–High (. 625)	Low-Moderate (. 375)
ALT	Moderate (. 5)	Moderate (. 5)	High (. 75)
THR	High (. 75)	Moderate–High (. 625)	Low-Moderate (. 375)
UTEC	Moderate (. 5)	Moderate (. 5)	Low-Moderate (. 375)
UPOL	Moderate (. 5)	Moderate (. 5)	Low-Moderate (. 375)
BAL	Moderate–High (. 625)	Moderate (. 5)	Low-Moderate (. 375)

Note: The values shown are for the final state of the variables in 1980; the initial state in 1970 was always "moderate", and the change toward the final state was uniform throughout the period until 1979.

CUL = cultural orientation towards collective as opposed to individual welfare

DEV = level of industrial development

SCA = perceived scarcity of resources and energy

POL = perceived level of pollution

ALT = possibility of (technological, geological) alternatives (within the region) to imports of resources and energy

THR = possibility of threat as a result of import dependence

UTEC = uncertainty about technological progress with respect to energy supply

UPOL = uncertainty about the harmful effects of pollution

BAL = negative balance of payments

fuel sources, new supplies, etc.), a decrease in perceived threat to imported supplies, a decrease in uncertainty about the development of new technologies to cope with problems and in uncertainty about the affects of pollution, and finally a small decrease in balance of payments problems. (See Table 6.3.) The effect of all of these changes contrasts markedly with the "worst case". Concern about imports largely disappears. On the other hand, with all of these problems alleviated, goals for the economic system increase markedly. The result is that by the end of the 10 year period major amounts of capital are being diverted from energy production to elsewhere in the economy. Again see Figure 6.4 and 6.5 for an overview of the policy made in response to this scenario.

The third scenario might be called the "most likely" case. Although exact details of the "most likely" future can be debated, a more moderate situation than that of the last two scenarios is probable. We posited moderate increases in pollution, scarcity, and threat to energy imports, in contrast to the major increases in the "worst possible scenario" (see Table 6.3). The result in terms of policies is also more moderate. Because there is some decrease in the goal for imports, the decision-making mechanism does transfer some money into energy. Yet there is not a major transfer because the other goals only decrease slightly, requiring the maintenance of most capital in those sectors. One of the most remarkable aspects of this "most likely" case is the stability of it. By 1972 the policy selected is a transfer of $ 4.71 billion into energy production. This policy decision remains unchanged for the remaining years of the decade.

These scenarios and cases cannot be given a great deal of weight. Both the economic and energy models upon which they were built and

See Table 6.3 for an explanation of the scenarios.

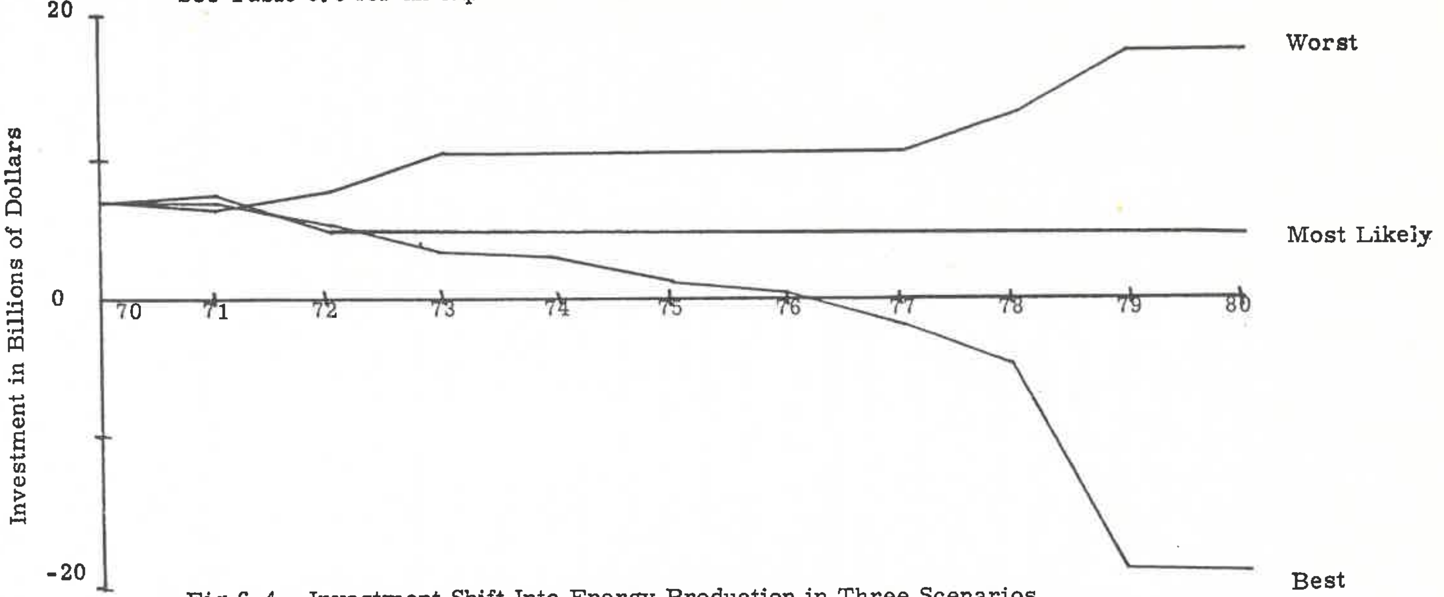


Fig 6.4 - Investment Shift Into Energy Production in Three Scenarios

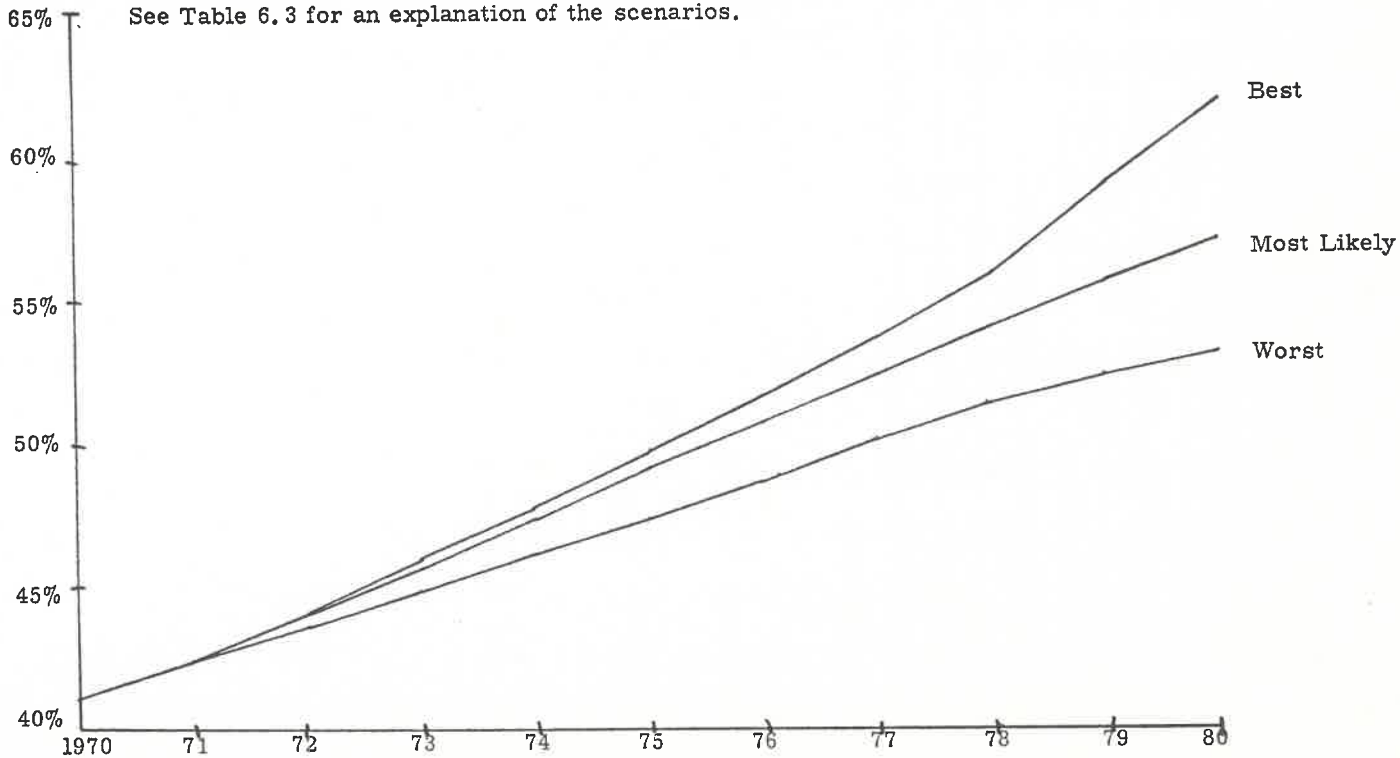


Fig 6.5 - Imports of Energy as a Percentage of Total Consumption in Three Scenarios

the model of the norms stratum need much further work. It is nevertheless impressive that a wide range of seemingly plausible and internally consistent situations can be generated and examined with the approach. A model without such explicit consideration and inclusion of human values could never be used as systematically to examine a range of possible energy futures. After seeing the wide variety of such futures it is hard to understand how analyses of the energy situation could ignore the major value questions.

Still the approach needs much further work, especially in more systematically developing the linkages between the environment and values, and between values and goals. It is to a brief discussion of such work that we now turn.

7. CONCLUSIONS

A great deal remains to be done in the creation of a fully acceptable value-based decision-making structure. The literature searches, data gathering efforts, and testing procedures which underly all simulation efforts must be carried further. What has been done and reported upon here hopefully shows the desirability and feasibility of the effort, but it is clearly only the beginning of that effort.

The search for advice and assistance in the literature on values and decision-making will continue. This work breaks such new ground, however, that only peripherally relevant materials can be expected in the literature. More fruitful than the ongoing formal literature search will be contacts with those who are currently researching the same issues and introduction to their work and unpublished writing.

This project calls also for a rather major data search. Specifically, the model requires data on values on the interrelationships or structures in value systems, on decision-maker goals (and their relative importance) and on past decision-making performance.

Data on values and value system structures are fragmentary and scattered. A search through a wide range of cross-national public opinion surveys (such as the Cantril surveys [1]), through assorted national surveys, and through literature on public opinion will be undertaken. Area specialists must also be counted on to provide assistance in formulating consistent value structures. Some case studies of past decision-making in problem situations will assist in the establishment of linkages between values, goals, and action.

Because of the close interrelationship of values, goals, and decision-making, much effort must be directed into tests of the entire approach, to supplement efforts at refining individual components. For instance, tests of the model against historic periods could prove very valuable. One interesting period for the energy policy of the Mideast and North African nations encompasses the formation of OPEC. In that period significant changes in values and policies occurred. Similarly, closings of the Suez canal might provide historical periods against which to test the impact of threat to imports on the values and actions of developed world decision-makers.

Future work will be directed towards creating two value-controlled decision-making structures which interact through competition and co-operation in the environments which they control. Specifically, we will simulate the decision-making of a developed oil-importing area (say the U.S.) and the oil-exporting (basically OPEC) countries. This should allow not only further development and testing of the approach, but should produce a useful research instrument.

In the process of this model development, effort will be directed not only at refining the parameters and structure embedded in the prototype model, but also at introducing some additional features. Many of these were discussed in this report, but time did not allow implementation in the prototype. Section 3 of this report discussed, for instance, the desirability of making the goal weights dependent upon the value structure and changes therein. Section 2 noted that various modes of operation, including mixes of interactive and completely simulated modes, should be available to the model user. A related improvement to the structure involves adding a dialogue between the computer simulation and the user in which the simulation extracts basic norms, or at least a set of goals and goal weights, from the interactor. This would allow a certain tailoring of the model to particular decision-makers.

Although there remains so much to do, the framework laid out in this report and the testing of that framework provided by the prototype model already constitute significant progress in an area where no prior efforts exist as guides. And as noted earlier, the marked impact of value changes on policy formation serve to reinforce the belief that any systematic study of energy or other world problem areas must incorporate the values and actions of decision-makers. Such efforts can and should continue.

Footnotes and References to Section 7

[1] Hadley Cantril has conducted survey research throughout the world on the "Patterns of Human Concern". These surveys are available through the Inter-University Consortium for Political Research at Ann Arbor, Michigan.

8. APPENDIX

Program Listing

```
C INITILIZATION OF NORMATIVE ROUTINE
      REAL IMPR(21),IMPA(21)
      DIMENSION A(4,4),A1(4,4),VF(4),P(4),R(4),D(4),QTF(14,4),
     2   AK0(4),Q0(4)
      DIMENSION AK(4),Q(4),V(4),X(4),Y(4),AIO(4),CEM(4),AID(4),
     2   RNORM(4),PNORM(4)
      DIMENSION EPR(21),ECR(21),EBR(21),EPPCR(21),ECPCR(21),GRPR(21)
     2   ,YIPCR(21),YSPCR(21)
      DIMENSION EPA(11),ECA(11),EBA(11),EPPCA(11),ECPCA(11),GRPA(11)
     2   ,YIPCA(11),YSPCA(11)
      DIMENSION EPP(11),ECP(11),EBP(11),EPPCP(11),ECPCP(11),GRPP(11)
     2   ,YIPCP(11),YSPCP(11)
      DIMENSION GOAL(6), WG(6),WY(10), SM(6),CIN(4), SICH(4),POLC(4),
     XPOLS(4),POL(4),POLI(4), CGOAL(6)
      COMMON A,A1,VF,P,R,D,QTF,TFM,AK0,Q0,POP0,POPR
      COMMON EPR,EBA,ECA,EPA,IY,EQREF,SY,EBR ,SI
      COMMON    ECR,    EPPCR,ECPCR,GRPR,YIPCR,YSPCR,
     2   EPPCA,ECPCA,GRPA,YIPCA,YSPCA,EPP,ECP,EBP,EPPCP,ECPCP,GRPP,
     3   YIPCP,YSPCP
      DATA GOAL /0.0,.025,.4,.025,.027,.035/
      DATA WG /0.0,0.0,1.0,1.0,1.0,0.0/
      DATA WY /1.0,.5,.25,0.0,.5,0.0,0.0,0.0,0.0,0.0/
      DATA SM /1.0,1.0,-1.0,1.0,1.0,1.0/
      DATA CIN / 5.,.1,.1,.1/
C
C         ---------- PASS A  ----------
C
C
C     READ DATA
C
      CALL ECONR
      READ (2,99) EQRED
99    FORMAT(4E10.3,4E10.3)
C
C     REFERENCE GENERATOR
C
      DO 100 I=1,4
      PNORM(I)=P(I)
      RNORM(I)=R(I)
      AK(I)=AK0(I)
100   Q(I)=Q0(I)
      POP=POP0
      DO 101 IY=1,21
      CALL ECONB(AK,Q,V,X,Y,SY,AIO,SI,CEM,AID)
      GRPR(IY)=SY
      EPR(IY)=15.*X(2)
      EPPCR(IY)=EPR(IY)/POP
      ECR(IY)=3.*SY
      ECPCR(IY)=ECR(IY)/POP
      EBR(IY)=ECR(IY)-EPR(IY)
      YSPCR(IY)=Y(4)/POP
      YIPCR(IY)=Y(3)/POP
101   CALL ECOND (AK,Q,X,AID,POP)
      DO 110 I=1,4
      P(I)=PNORM(I)
```

```
      R(I)=RNORM(I)              C 106
      AK(I)=AK0(I)
  110 Q(I)=Q0(I)
      DO 102 IY=1,21
      XY=IY-1
      OBP=2.75*(1.+(XY   )*.05)
  102 IMPR(IY)=EBR(IY)*.0048*OBP
C
C     INTRODUCTION
C
      WRITE (3,21)
21    FORMAT(10X,'=== M-P WORLD MODEL DEMONSTRATION ===',/,
     X20X,'- ECONOMIC SECTOR -',/20X,'- DEVELOPED REGION -',10X,/,
     X/,9X,'CRISIS MONITORING IN THE ENERGY SECTOR ',//)
C INITILIZATION OF ECONOMIC AND ENERGY ROUTINES
C     INITIAL POLICY CHOICE
      POL(1)=7.
      POL(2)=50.
      POL(3)=40.
      POL(4)=10.
      NSTR=4
      NSTR2=3
      EQREF =EQRED
      QMUL=1.
      IY=1
      IYR=1970
      FNO=1.
      CM=1.
 2754 CONTINUE
      SP=0.
C GOAL CHANGE ROUTINE
C     ALLOW INTERACTIVE SETTING
C     CHANGE FROM ENVIRONMENT
C     INITIAL GOALS
      DO 112 I=1,6
  112 CGOAL(I)=0.
      CALL NORMS (CGOAL,IYR)

      DO 2750 I=2,6
 2750 GOAL(I)=GOAL(I)*(1.+CGOAL(I))
C TEMPORARY CAR--THIS VALUE FROM REGION 2
      XY=IY-1
      OBP=2.75*(1.+(XY   )*.05)
      DO 209 I=1,4
      P(I)=PNORM(I)
209   R(I)=RNORM(I)
      Q(2)=Q(2)*QMUL
      QMUL=QMUL*EQREF
      IF(QMUL-.5)310,310,311
310   QMUL=.5
      EQREF =1.0
311   CONTINUE
      CALL ECONB(AK,Q,V,X,Y,SY,AIO,SI,CEM,AID)
      EPA(IY)=15.*X(2)
      ECA(IY)=3.*SY
      EBA(IY)=ECA(IY)-EPA(IY)
      IMPA(IY)=EBA(IY)*.0045*OBP
      EPPCA(IY)=EPA(IY)/POP
      ECPCA(IY)=ECA(IY)/POP
      YIPCA(IY)=Y(3)/POP
      YSPCA(IY)=Y(4)/POP
      GRPA(IY)=SY
C     CHANGE ACCORDING TO SUCCESS
      IF (IY-2) 208,207,207
  207 IC=2
      IX=IY-1
```

```
      GAP=GOAL(2)-ECPCA(IY)/ECPCA(IX)+1.
      GO TO 200
  210 GAP=EBA(IY)/ECA(IY)-GOAL(3)
      GO TO 200
  212 GAP=GOAL(4)-YIPCA(IY)/YIPCA(IX)+1.
      GO TO 200
  214 GAP=GOAL(5)-YSPCA(IY)/YSPCA(IX)+1.
      GO TO 200
  216 GAP=GOAL(6)-GRPA(IY)/GRPA(IX)+1.
  200 IF (GAP) 202,204,206
  202 GOAL (IC)=GOAL(IC)-.25*GAP*SM(IC)
      GO TO 204
  206 GOAL (IC)=GOAL(IC)-.1*GAP*SM(IC)
  204 IC=IC+1
      GO TO (208,208,210,212,214,216,208), IC
  208 CONTINUE
      DO 220 I=1,6
      IF (GOAL(I)-.01) 222,220,220
  222 GOAL (I)=.01
  220 CONTINUE
      WRITE (3,505) IYR
505   FORMAT(1X,'THIS IS YEAR',I5,/)
C ACTIVATE LAST YEARS POLICY MIX AND PROJECT IMPACT
      DO 330 I=1,4
  330 SICH(I)=0.
      AKTM=POL(1)
      X1=POL(2)
      X2=POL(3)
      X3=POL(4)
      CALL TRANS (AKTM,X1,X2,X3,NSTR,NSTR2,AK,Q,POP,QMUL,GRPP,EPP,ECP,
     2EBP,EPPCP,ECPCP,YIPCP,YSPCP,AID,AIO,CEM)
      CALL EVAL(EBP,ECP,ECPCP,GRPP,YIPCP,YSPCP,GOAL,WG,WY,SM,CIN,
     XSICH,AKTM,X1,X2,X3,DIS,SP)
      WRITE (3,389) AKTM,X1,X2,X3,DIS
C POLICY SEARCH PROCEDURE--CAPITAL TRANSFER FIRST
      SDIS=DIS
      IF (DIS-500.) 343,343,340
  340 DIS=500.
  343 ISL=DIS/20.
      POLC(1)=DIS/200.
      DO 350 I=2,4
  350 POLC(I)=DIS/100.
      DIS=SDIS
      KK=0
      DISO=DIS/2.
      POLI(1)=AKTM
      POLI(2)=X1
      POLI(3)=X2
      POLI(4)=X3
  354 IPO=0
C BEGINNING OF SEARCH PROPER
  357 IPO=IPO+1
      IS=1
      ST=1.
  356 ISC=0
  358 DO 360 I=1,4
  360 POLS(I)=POL(I)
      SDIS=DIS
      ISC=ISC+1
      IF (ISC-ISL) 367,410,410
  367 POL (IPO)=POL(IPO)+POLC(IPO)*ST
      IF (IPO-1) 370,361,370
  361 IF (POL(1)-25.) 362,362,410
  362 IF (POL(1)+20.) 410,385,385
C CHECK ON SEARCH BOUNDARIES
  370 IF (POL(IPO)-99.) 372,410,410
```

```
  372 IF (POL(IPO)) 410,375,375
C ADJUST X1,X2,X3
  375 IF (IPO-2) 377,376,377
  376 IP1=3
      IP2=4
      GO TO 380
  377 IF (IPO-3) 379,378,379
  378 IP1=2
      IP2=4
      GO TO 380
  379 IP1=2
      IP2=3
  380 PP=POL(IP1)/(POL(IP1)+POL(IP2))
      POL(IP1)=POL(IP1)-POLC(IPO)*PP*ST
      POL(IP2)=POL(IP2)-POLC(IPO)*(1.-PP)*ST
  385 CONTINUE
C EVALUATE POLICY
      AKTM=POL(1)
      X1=POL(2)
      X2=POL(3)
      X3=POL(4)
      DO 387 I=1,4
  387 SICH(I)=ABS(POLI(I)-POL(I))
      CALL RESET (AK,Q,V,X,Y,SY,AIO,SI,CEM,AID,PNORM,RNORM)
      CALL TRANS (AKTM,X1,X2,X3,NSTR,NSTR2,AK,Q,POP,QMUL,GRPP,EPP,ECP,
     2EBP,EPPCP,ECPCP,YIPCP,YSPCP,AID,AIO,CEM)
      CALL EVAL(EBP,ECP,ECPCP,GRPP,YIPCP,YSPCP,GOAL,WG,WY,SM,CIN,
     XSICH,AKTM,X1,X2,X3,DIS,SP)
      WRITE (3,389) AKTM,X1,X2,X3,DIS,KK
  389 FORMAT (5F10.2,I4,/)
      C=SDIS-DIS
      IF (C-CM) 395,395,358
C WHEN NEW POLICY IS UNSATISFACTORY
  395 DO 397 I=1,4
  397 POL(I)=POLS(I)
      DIS=SDIS
      IF (ISC-1) 413,398,413
  398 IF (IS-1 ) 413,400,413
  400 ST=-1.
      IS=-1
      GO TO 356
C WHEN LIMIT OF TRIES IS REACHED OR SEARCH BOUNDARY IS EXCEEDED
  410 POL(IPO)=POLS(IPO)
  413 IF (IPO-4) 357,414,414
  414 IF (DIS-100.) 416,418,418
  416 IF (DIS-DISO) 418,418,425
  418 IF (KK) 419,419,425
  419 KK=1
      DO 422 I=1,4
  422 POLC(I)=POLC(I)/2.
      GO TO 354
  425 CONTINUE
      SP=2.
      AKTM=POL(1)
      X1=POL(2)
      X2=POL(3)
      X3=POL(4)
      CALL RESET (AK,Q,V,X,Y,SY,AIO,SI,CEM,AID,PNORM,RNORM)
      CALL TRANS (AKTM,X1,X2,X3,NSTR,NSTR2,AK,Q,POP,QMUL,GRPP,EPP,ECP,
     2EBP,EPPCP,ECPCP,YIPCP,YSPCP,AID,AIO,CEM)
      CALL EVAL(EBP,ECP,ECPCP,GRPP,YIPCP,YSPCP,GOAL,WG,WY,SM,CIN,
```

```
     XSICH,AKTM,X1,X2,X3,DIS,SP)
C  IMPLEMENT
      IY=IY+1
      IYR=IYR+1
      IF (IY-11) 2828,2828,2830
 2828 CALL ECOND  (AK,Q,X,AID,POP)
      GO TO 2754
 2830 CONTINUE
      CALL EXIT
      END
```

```
      SUBROUTINE EVAL (EBP,ECP,ECPCP,GRPP,YIPCP,YSPCP,GOAL,WG,WY,SM,CIN,
     XSICH,AKTM,X1,X2,X3,DIS,SP)
      DIMENSION EBP(11),ECP(11),ECPCP(11),YIPCP(11),YSPCP(11),GRPP(11)
      DIMENSION PROJ(6,10),WG(6),WY(10),SM(6),CIN(4),SICH(4),GOAL(6)
      DO 100 I=2,11
      K=I-1
      PROJ(2,K)=ECPCP(I)/ECPCP(K)-1.
      PROJ(3,K)=EBP(I)/ECP(I)
      PROJ(4,K)=YIPCP(I)/YIPCP(K)-1.
      PROJ(5,K)=YSPCP(I)/YSPCP(K)-1.
  100 PROJ (6,K)=GRPP(I)/GRPP(K)-1.
      DIS=0.
      SC=0.
      DO 102 I=2,6
      DO 102 J=1,10
      TUM=(GOAL(I)-PROJ(I,J))*SM(I)
      IF (TUM) 104,104,103
  103 WF=WG(I)*WY(J)
      DIS=DIS+WF*(TUM/GOAL(I)*100.)**2.
  104 SC=SC+WF
  102 CONTINUE
      DIS=DIS/SC
      CI=0.
      DO 105 I=1,4
  105 CI= CI+CIN(I)*SICH(I)
      DIS=DIS+CI
      IF (SP-1.) 2752,2752,2719
 2719 WRITE (3,2720)
 2720 FORMAT(/, 16X,4HECPC,8X, 2HIM,6X,4HYIPC,6X, 4HYSPC,7X,3HGRP)
      WRITE (3,2722) (GOAL(I),I=2,6)
 2722 FORMAT (2X,5HGOALS, 3X,5(4X,F6.3))
      WRITE (3,2724) (PROJ(I,1),I=2,6)
 2724 FORMAT (2X, 9HPROJECTED, 3X, F6.3,4(4X,F6.3))
      WRITE (3, 2728)
 2728 FORMAT (/,10X,4HAKTM,6X,2HX1,6X,2HX2,6X,2HX3)
      WRITE (3, 2729) AKTM,X1,X2,X3
 2729 FORMAT ( 7X, 4(2X,F6.2))
      WRITE (3,2750) DIS
 2750 FORMAT (/,2X,  27HAVERAGE DISSATISFACTION IS   ,F10.0,/,/,/)
 2752 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TRANS (AKTM,X1,X2,X3,NSTR,NSTR2,AK,Q,POP,QMUL,GRP,
     2EPP,ECP,EBP,EPPCP,ECPCP,YIPCP,YSPCP,AID,AIO,CEM)
      DIMENSION EPP(11),ECP(11),EBP(11),EPPCP(11),ECPCP(11),YIPCP(11),
     XYSPCP(11),AID(4),AIO(4),CEM(4)
      DIMENSION A(4,4),A1(4,4),VF(4),P(4),R(4),D(4),QTF(14,4),
     2   AKO(4),Q0(4)
      DIMENSION AK(4),Q(4),EPR(21),EBA(11),ECA(11),EPA(11),EBR(21)
      COMMON A,A1,VF,P,R,D,QTF,TFM,AKO,Q0,POPO,POPR
      COMMON EPR,EBA,ECA,EPA,IY,EQREF,SY,EBR ,SI
      AK2P=AK(2)+AID(2)-D(2)*AK(2)
      GO TO (361,362,365,362),NSTR
362   GO TO (365,366,369),NSTR2
365   EPNXT=EPR(IY+1)
      GO TO 367
366   EPNXT=EPR(IY+1)-((EBR(IY)-EBA(IY))/ECA(IY))*EPA(IY)
367   AKNXT=EPNXT*(AK(2)/EPA(IY))/EQREF
      AKTM=AKNXT-AK2P
  369 AID(2)=AID(2)+AKTM
      GO TO (361,372,373,372),NSTR
372   AID(3)=AID(3)-AKTM*(X1/100.)
      AID(4)=AID(4)-AKTM*(X2/100.)
      IF (NSTR-4) 371,373,371
373   AIO(3)=AIO(3)+AKTM*(X3/100.)
      CEM(3)=CEM(3)-AKTM*(X3/100.)
      P(3)=AIO(3)/SY
      SI=SI+AKTM*X3/100.
371   R(2)=AID(2)/SI
      R(3)=AID(3)/SI
      R(4)=AID(4)/SI
361   CONTINUE
      CALL PREDI (AK,Q,POP,QMUL,GRP,EPP,ECP,EBP,EPPCP,ECPCP,YIPCP,
     XYSPCP)
      RETURN
      END
```

```
      SUBROUTINE NORMS(CGOAL,IYR)
      REAL NUVAL(6),NUGOL(5),NUVAR(10)
      DIMENSION CGOAL(6),DGOL(5)
      DIMENSION W(6,15),OLVAL(6),DVAR(9),DVAL(6),       OLVAR(9)
      DIMENSION U(5,6),OLGOL(5),SVVAR(9),SVVAL(6),SVGOL(5)
      DIMENSION W1(15),W2(15),W3(15),W4(15),W5(15),W6(15)
      DIMENSION U1(6),U2(6),U3(6),U4(6),U5(6)
C     NOTE  VARIABLES, VALUES, GOALS ARE ALWAYS LISTED IN FOLL. ORDER
C          CUL, DEV, SCA, POL, ALT, THR, UTEC, UPOL, BAL
C          VFUT, VIMP, VEFF, VPOL, VMAT, VSER
C          GECPC, GIM, GYIPC, GYSPC, GGRP
C     INFLUENCE MATRIX FOR VALUES (*8.)
C          BOSSEL 10 AUG 73  MOD. 15 AUG.
      DATA W1 /6.,3.,6.,4.,-3.,5.,3.,3.,4.,0.,3.,3.,4.,-2.,-1./
      DATA W2 /0.,2.,6.,-1.,-5.,7.,3.,0.,6.,2.,0.,0.,0.,-2.,0./
      DATA W3 /1.,2.,6.,2.,-2.,5.,3.,1.,1.,5.,2.,0.,1.,-2.,0./
      DATA W4 /2.,2.,-1.,6.,0.,0.,-1.,6.,0.,5.,0.,0.,0.,-4.,3./
      DATA W5 /-2.,6.,-1.,-2.,0.,-1.,-1.,-1.,-1.,-1.,-1.,-2.,-2.,0.,2./
      DATA W6 /4.,5.,-1.,0.,0.,0.,0.,2.,-1.,0.,0.,0.,2.,4.,0./
C     INFLUENCE MATRIX FOR GOALS (*8.)
C          BOSSEL/HUGHES 15 AUG 73
      DATA U1 /0.,-4.,-3.,-2.,3.,2./
      DATA U2 /0.,-7.,-1.,0.,2.,0./
      DATA U3 /0.,0.,-1.,-2.,6.,3./
      DATA U4 /1.,0.,0.,-2.,3.,7./
      DATA U5 /0.,1.,-1.,-1.,5.,3./
C     INITIAL VALUES FOR VARIABLES
      DATA SVVAR /.5,.5,.5,.5,.5,.5,.5,.5,.5/
C     INITIAL VALUES FOR VALUES
      DATA SVVAL /.5,.5,.5,.5,.5,.5/
C     INITIAL VALUES FOR GOALS
      DATA SVGOL /.0,.0,.0,.0,.0/
      DO 10 I=1,15
      C=0.625
      CC=1.0
      W(1,I)=W1(I)/8.*C
      W(2,I)=W2(I)/8.*C
      W(3,I)=W3(I)/8.*C
      W(4,I)=W4(I)/8.*C
      W(5,I)=W5(I)/8.*C
      W(6,I)=W6(I)/8.*C
   10 CONTINUE
      DO 12 I=1,6
      U(1,I)=U1(I)/8.*CC
      U(2,I)=U2(I)/8.*CC
      U(3,I)=U3(I)/8.*CC
      U(4,I)=U4(I)/8.*CC
      U(5,I)=U5(I)/8.*CC
   12 CONTINUE
      DO 110 I=1,9
      OLVAR(I)=SVVAR(I)
      DVAR(I)=0.0
  110 CONTINUE
      DO 120 I=1,6
      OLVAL(I)=SVVAL(I)
      DVAL(I)=0.0
  120 CONTINUE
      DO 130 I=1,5
      OLGOL(I)=SVGOL(I)
  130 CONTINUE
```

```
      INYEA=1970
      ISTEP=1
      DT=ISTEP
      IYEAR=INYEA-ISTEP
      IEND=1+IYR-1970
C     BEGIN COMPUTATION
      DO 888 ICOUN=1,IEND
      IYEAR=IYEAR+ISTEP
      IYEA=IYEAR
      NUVAR(1)=SVVAR(1)+(IYEA-INYEA)*.0
      NUVAR(2)=SVVAR(2)+(IYEA-INYEA)*.0
      NUVAR(3)=SVVAR(3)+(IYEA-INYEA)*.0
      NUVAR(4)=SVVAR(4)+(IYEA-INYEA)*.025
      NUVAR(5)=SVVAR(5)+(IYEA-INYEA )*.0
      NUVAR(6)=SVVAR(6)+(IYEA-INYEA)*.0
      NUVAR(7)=SVVAR(7)+(IYEA-INYEA)*.0
      NUVAR(8)=SVVAR(8)+(IYEA-INYEA)*.0
      NUVAR(9)=SVVAR(9)+(IYEA-INYEA)*.0
      DO 145 ICASA=1,9
      DVAR(ICASA)=NUVAR(ICASA)-OLVAR(ICASA)
  145 CONTINUE
      VAP=0.0
      CALL VALUS(OLVAL,NUVAL,DVAR,DVAL,W,DT)
      CALL GOALX(OLGOL,NUGOL,DVAL,U,DT,DGOL)
      IF (IYEAR-IYR) 147,148,999
  148 WRITE (3,150) IYEAR,VAP,(NUVAL(I),I=1,6),(NUGOL(I),I=1,5)
  150 FORMAT (1H0,I5,F9.2,F10.2,10F7.2)
  147 CONTINUE
      DO 160 I=1,6
      OLVAL(I)=NUVAL(I)
  160 CONTINUE
      DO 162 I=1,5
      OLGOL(I)=NUGOL(I)
  162 CONTINUE
      DO 164 I=1,9
      OLVAR(I)=NUVAR(I)
  164 CONTINUE
  888 CONTINUE
      CGOAL(1)=0.0
      DO 200 I=2,6
      IMIN=I-1
      CGOAL(I)= DGOL(IMIN)
  200 CONTINUE
  999 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE VALUS(OLVAL,NUVAL,DVAR,DVAL,W,DT)
      REAL NUVAL(6)
      DIMENSION OLVAL(6),          DVAR(9),DVAL(6),W(6,15)
      DIMENSION SDVAR(6),SDVAL(6)
      DO 10 IVAL=1,6
      SUM=0.0
      DO 20 IVAR=1,9
      SUM=SUM+DVAR(IVAR)*W(IVAL,IVAR)*DT
   20 CONTINUE
      SDVAR(IVAL)=SUM
      SUM=0.0
      DO 30 ISUM=1,6
      IMAT=ISUM+9
      SUM=SUM+DVAL(ISUM)*W(IVAL,IMAT)*DT
   30 CONTINUE
      SDVAL(IVAL)=SUM
      DVAL(IVAL)=SDVAR(IVAL)+SDVAL(IVAL)
      NUVAL(IVAL)=OLVAL(IVAL)+DVAL(IVAL)
   10 CONTINUE
      RETURN
      END


      SUBROUTINE GOALX(OLGOL,NUGOL,DVAL,U,DT,DGOL)
      REAL NUGOL(5)
      DIMENSION U(5,6),OLGOL(5),          DVAL(6)
      DIMENSION DGOL(5)
      DO 10 IGOL=1,5
      SUM=0.0
      DO 20 IVAL=1,6
      SUM=SUM+DVAL(IVAL)*U(IGOL,IVAL)*DT
   20 CONTINUE
      DGOL(IGOL)=SUM
      NUGOL(IGOL)=OLGOL(IGOL)+DGOL(IGOL)
   10 CONTINUE
      RETURN
      END


      SUBROUTINE ECONR
C
C     READS IN THE DATA FOR THE SHORT ECONOMUC MODEL
C
      DIMENSION A(4,4),A1(4,4),VF(4),P(4),R(4),D(4),QTF(14,4),
     2   AK0(4),Q0(4)
      COMMON A,A1,VF,P,R,D,QTF,TFM,AK0,Q0,POP0,POPR
      READ (2,100) A,A1,VF
      READ (2,100) AK0
      READ (2,100) D
      READ (2,100) R
      READ (2,100) P
      READ (2,100) Q0
      DO 4 I=1,4
    4 READ (2,100) (QTF(J,I),J=1,14)
      DO 3 IS=1,3
      DO 3 IR=1,7
    3 READ (2,100) (TFM,J=1,14)
      READ (2,100) POP0,POPR
100   FORMAT(4E10.3,4E10.3)
      RETURN
      END
```

```
      SUBROUTINE ECOND (AK,Q,X,AID,POP)
C
C     ADVANCES THE ECOMIC MODEL TO THE NEXT TIME STEP
C
      DIMENSION AK(4),Q(4),X(4),AID(4)
      DIMENSION A(4,4),A1(4,4),VF(4),P(4),R(4),D(4),QTF(14,4),
     2   AK0(4),Q0(4)
      COMMON A,A1,VF,P,R,D,QTF,TFM,AK0,Q0,POP0,POPR
      DO 11 I=1,4
      Q(I)=TABFU (X(I),QTF(1,I))
      AK(I)=AK(I)+AID(I)-D(I)*AK(I)
 11   CONTINUE
      POP=POP+POPR
      RETURN
      END


      SUBROUTINE RESET (AK,Q,V,X,Y,SY,AIO,SI,CEM,AID,PNORM, RNORM)
      DIMENSION AK(4),Q(4),V(4),X(4),Y(4),AIO(4),CEM(4),AID(4)
      DIMENSION A(4,4),A1(4,4),VF(4),P(4),R(4),D(4),QTF(14,4),
     2   AK0(4),Q0(4),PNORM(4),RNORM(4)
      COMMON A,A1,VF,P,R,D,QTF,TFM,AK0,Q0,POP0,POPR
      DO 2 I=1,4
      R(I)=RNORM(I)
    2 P(I)=PNORM(I)
      CALL ECONB (AK,Q,V,X,Y,SY,AIO,SI,CEM,AID)
      RETURN
      END


      SUBROUTINE PREDI (AK0,Q0,POP0,QMUL,GRP,EP,EC,EB,EPPC,ECPC,
     2   YIPC,YSPC)
      DIMENSION AK0(4),Q0(4),EP(11),EC(11),EB(11),EPPC(11),ECPC(11)
      DIMENSION AK(4), Q(4),V(4),X(4),Y(4),AIO(4),CEM(4),AID(4)
      DIMENSION YIPC(11),YSPC(11),GRP(11)
      DO 400 J=1,4
      AK(J)=AK0(J)
 400  Q(J)=Q0(J)
      Q(2)=Q(2)/QMUL
      POP=POP0
      DO 401 JYL=1,11
      Q(2)=Q(2)*QMUL
      CALL ECONB(AK,Q,V,X,Y,SY,AIO,SI,CEM,AID)
      EP(JYL)=15.*X(2)
      EC(JYL)=3.*SY
      EB(JYL)=EC(JYL)-EP(JYL)
      EPPC(JYL)=15.*X(2)/POP
      ECPC(JYL)=3.*SY/POP
      YIPC(JYL)=Y(3)/POP
      YSPC(JYL)=Y(4)/POP
      GRP(JYL)=SY
 401  CALL ECOND (AK,Q,X,AID,POP)
      RETURN
      END
```

```
      SUBROUTINE ECONB(AK,Q,V,X,Y,SY,AIO,SI,CEM,AID)
C
C     COMPUTES ALL THE ECONOMIC INFORMATION FOR A SINGLE TIME STEP
C     DOES NOT COMPUTE IMPORT INFO
C
      DIMENSION AK(4),Q(4),V(4),X(4),Y(4),AIO(4),CEM(4),AID(4)
      DIMENSION A(4,4),A1(4,4),VF(4),P(4),R(4),D(4),QTF(14,4),
     2   AKO(4),QO(4)
      COMMON A,A1,VF,P,R,D,QTF,TFM,AKO,QO,POPO,POPR
      DO 8 I=1,4
      V(I)=Q(I)*AK(I)
8     X(I)=V(I)/VF(I)
      DO 12 I=1,4
      Y(I)=0.0
      DO 12 J=1,4
12    Y(I)=Y(I)+A1(J,I)*X(J)
      SY=Y(1)+Y(2)+Y(3)+Y(4)
      DO 13 I=1,4
13    AIO(I)=P(I)*SY
      SI=AIO(1)+AIO(2)+AIO(3)+AIO(4)
      DO 14 I=1,4
      CEM(I)=Y(I)-AIO(I)
14    AID(I)=R(I)*SI
      RETURN
      END
```

```
      FUNCTION TABFU (XDIN,PAR)
C
C     COMPUTES TABLE FUNCTIONS
C
      DIMENSION X(7),Y(7),PAR(14)
      XD=XDIN
      DO 1 I=1,7
      J=(I-1)*2
      X(I)=PAR(J+1)
1     Y(I)=PAR(J+2)
      DO 2 I=1,7
      IF (XD-X(I)) 3,3,2
2     CONTINUE
      I=8
3     GO TO (4,5,5,5,5,5,5,6) ,I
4     TABFU =Y(1)
      GO TO 9
6     TABFU =Y(7)
      GO TO 9
5     DX=X(I)-X(I-1)
      TABFU =Y(I-1)*(X(I)-XD)/DX+Y(I)*(XD-X(I-1))/DX
9     RETURN
      END
```

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VI.2. AN APPROACH TO THE SIMULATION OF VALUE-SYSTEM AND VALUE-CHANGES

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Report prepared with the assistance of Hartmut Bossel at the Institute fuer Systemtechnik und Innovations-forschung (ISI) Karlsruhe, Germany, for his project UTOPIA

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1. Introduction

This paper undertakes to define an approach to a monumental problem: precise conceptualization and eventual computer simulation of governmental interaction with and control of its economic, social, and physical environment. Such an approach must be concerned not just with governmental decision mechanisms, but also, and perhaps more importantly, with the values and beliefs of society and decision-makers which act through those structures and processes to shape policy.

The operation of government and other organizational mechanisms has received considerable attention.[1] That is not to say that complete understanding has been achieved. Yet the problems of the normative component in decision-making have received far less attention, and even lack definition. In the organizational literature, perhaps the overwhelming emphasis on profit explains the phenomenon of inattention to values. Perhaps in political science and the other social sciences, the behavioral revolution and its emphasis on value-free research has led to some hesitance to do research on values. Clearly, however, societal and decision-maker values, norms, beliefs, and attitudes (or whatever other items describe the affective and cognitive conceptualizations of the human system) are both antecedent to and controlling within institutions and processes of decision-making. We need the ability to represent the role of general values and specific goals, from human needs to survive and be loved to desires for lower levels of atmospheric CO_2 and higher annual kilowatt usage capita, if we are to understand the directions in which societies and governments move.

The motivation to undertake the almost incredible task of this paper comes in part, of course, from the intellectual stimulation of the problem. Part of the motivation is, however, even more immodest. If a reasonable conceptual framework of the problems can be developed, and an approach to precise representation refined, then policy analysis can be the result. Somehow, a set of values and beliefs are translated into a set of policies. Understanding that translation process means greater ability to assist it.

This research and writing has been done in the context of the Mesarovic-Pestel World Model Project.[2] That project seeks to develop a ten region representation of the world, with each region represented in a multilevel, hierarchical fashion. The layers of the model, as represented in Figure 1.1, can be collapsed into three basic strata: the causal stratum, including the biological ecosystem and non-political human systems such as the economic; the organizational stratum, including political processes; and the normative stratum, reflecting basic human biological needs and more general values. This paper should thus serve the needs of that project for an approach to the simulation of the normative stratum and its control of the organizational stratum. It would be highly desireable to have a framework general enough to permit two modes of operation. First, a mode which represents regional norms and attitudes as accurately as possible and which will allow us to describe and project regional decision-making. Second, a mode which will allow the input of model user values, so that the Mesarovic-Pestel model can suggest the likely policies and their consequences given a system run by such values, as well as the most desireable policies and consequences given any set of values (The two policy sets need not be the same, since policies can contradict the very values in whose name they were applied).

More specifically, this research was done as part of Dr. Hartmut Bossel's related project on the study of norms and norm change.[3] For a general description of the total project and all of the elements involved in any information processing system, see his companion paper to this report.

This study will procede in the following manner. First we will look at some of the literature relevant to the study of values, their change, and their relation to decision-making. Then we will move into an effort to clarify the basic value-related concepts in this report. This introduction has made no effort to do so, since values, norms, beliefs, attitudes, goals, and other terms require very considerable definition. Next we will examine a number of potential general approaches to the actual operationalization of these concepts, trying to identify the major problems involved in any such effort. Two such problems, which will deserve special attention, are the non-orthogonality or intercorrelation of various value dimensions and the difficulty of dealing with values connected to uncertain outcomes. As an example of the later problem, consider the difficulty of evaluating energy related indicators when the possibility of Arab oil embargoes exists. The next chapter will develop a specific approach to the operationalization of affective concepts. After that we will turn out attention to the especially difficult area of value change over time. Unless our approach is to have only very short-run utility, such value change processes must be represented. Finally, we will address the linkage to decision-making, the procedures by which the values and beliefs of society and decision-makers are translated into policy. That is no simple task, either. We want to understand the transformation from a set of environmental states, across some set of indicators, to a set of policies. Even given knowledge of the values placed on various environmental states, there are difficulties. For instance, there are potentially many policies which would lead to states of the system with essentially comparable value satisfaction levels. On what basis is one selected?

These are the tasks of this report. It is presented in the hope that the ideas herein can be of some value, and with the hope that reader reactions will help create something especially useful.

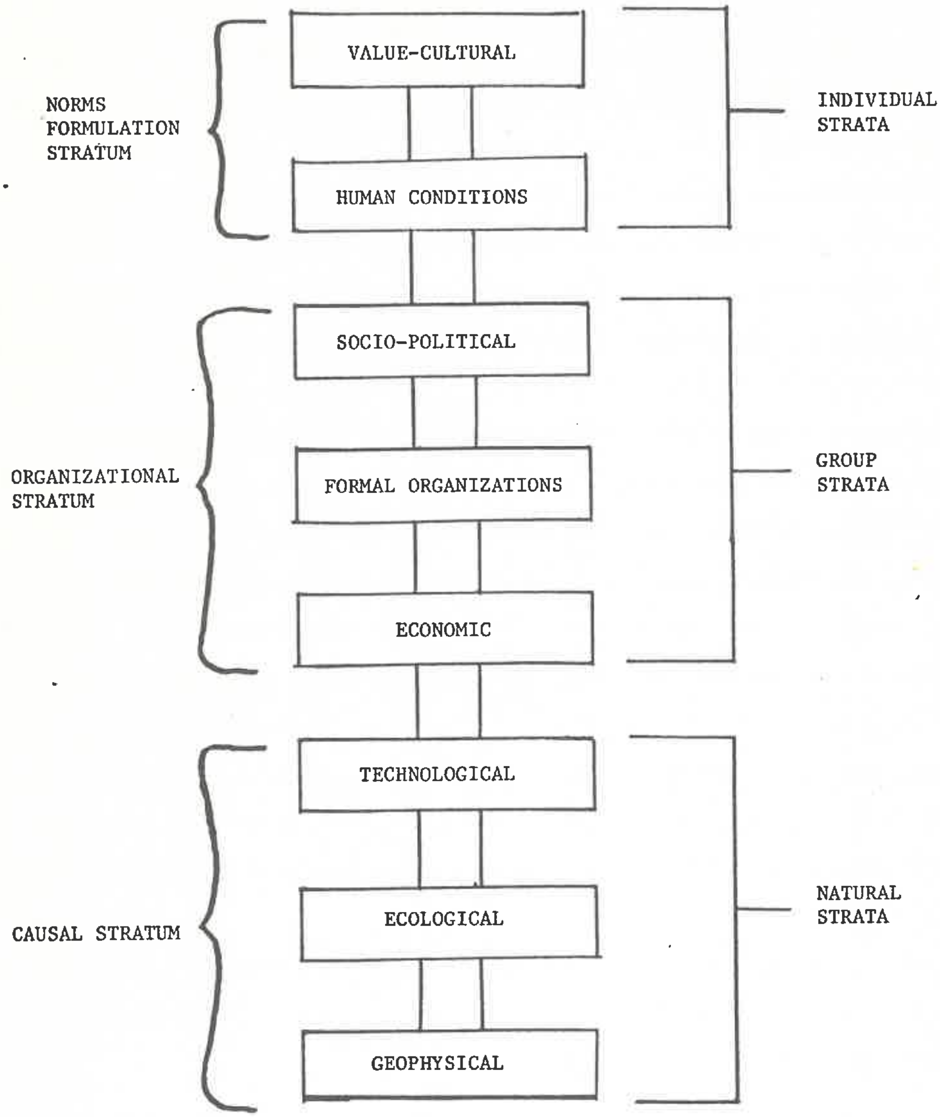


FIGURE 1.1. LEVELS OF THE WORLD MODEL

2. Literature on Values

This chapter preliminarily discusses the literature relevant to the study of human values. Project UTOPIA encompasses a very broad effort to utilize the relevant research and thought from the many disciplines and sub-disciplines it toüches. Reports from that effort will later greatly expand this initial outline. For ease of discussion, a categorization of literature has been made. As usual, this categorization will obscure and mispresent the works and meanings of scholars as well as clarify. Since the fields of sociology and psychology are potentially the behavioral sciences most relevant to the study, they are examined first. Philosophers have quite naturally been intensely involved in thought about values. They should aid us in conceptualization, and since they do not suffer from the "fear" of values evident in behavioral research, they may also add some important empirical insights to those of sociologists and psychologists. A fourth group of studies on which I want to focus are the social indicator efforts. Scholars in that area have taken the governance of society by values for granted, and have sought to develop indicators of the satisfaction of those values. On the surface, such efforts might appear especially relevant to the current project. In fact, they can make a significant contribution, but frequently lack the conceptualization and structure which this project requires, and on which the philosophers and social scientists offer more promise. Finally, the project will require massive data efforts for the construction and testing of its model. The last section of this chapter will thus turn to some largely atheoretic, but extremely useful data collections.

A. Sociology

The sociological contribution to our understanding of values can be quite clearly differentiated from the psychological. Whereas psychologists focus on the role that values play in the determination of individual human behavior, sociologists seek the importance of values to societal behavior and to the behavior of humans within a societal context. Some scholars in both disciplines have in common, however, a tendency to see values from a functional perspective. Individuals and societies have basic "needs," the most obvious and basic of which is survival. Values placed on various aspects of their environment including societal and political processes tend both to reflect those needs and to serve them.

Consider, for instance, the functional theory of Talcott Parsons. He lists four functions which are performed within or by social systems:[4]

> A - The Adaptive function, the system's handling of objects to provide itself with the means to deal with the exigencies of its (changing) situation and to pursue its goals;
>
> G - the performance of achieving its Goals;
>
> I - the Integration of the member actors and groups into a cohesive system; and
>
> L - the maintenance of cultural patterns characteristic of the system; this maintenance is considered "Latent" in the sense that both the patterns and their inculcation usually remain implicit, except for certain active phases of the (motivational) system in which their reaffirmation is made explicit.

These four functions clearly do require societal-relevant individual values and institutions if society is to survive. They do not, of course, necessarily require any one set of institutions or values. This brings us to the set of questions to which this project would like answers: What kinds of value sets guide societies? How much and what kind of variation among societies is compatible with societal maintenance? What are the mechanisms by which institutions and values guide societies? How do values change?

Parsons does not directly attack these questions. He has, however, moved in directions which have potential relevance for us. For one thing, in looking at differences among social systems, he has tried to identify types of social institutions, and has suggested three basic ones:

1. cultural institutions
2. regulative institutions
3. relational institutions

Each of these "institutions" is largely informal and value based, not formally structured. Types of values can be associated with each--for instance, systems of expressive symbols with cultural institutions and reciprocal role expectations with relational institutions. To the best of my knowledge, however, Parsons has not operationalized the various value components of these institutions so as to allow us to describe various societies in terms of them or to procede to general typologies of societies.

Another conceptualization within which inter-society differences and patterns can be sought also comes from Parsons, in conjunction with Shils. These are the pattern variables.[5]

1. Affectivity vs. Affective neutrality
2. Universalism vs. Particularism
3. Self-orientation vs Collectivity-orientation
4. Asciption vs Achievement
5. Diffuseness vs Specificity

These pattern variables define dimensions of relational activity--man to man and man to society, and they suggest clear value clusters. Again I am not aware of the degree to which these clusters have been specified and operationalized.

Although this functionalist sociological literature thus has a clear orientation towards values, there are some problems connected with our use of it. Most importantly, the literature focuses very largely on values in the context of societal relations and societal maintenance. These values are, of course, critical. Yet our concern with values is more general--not just with values important to the social system, but with values flowing from basic physiological needs (e.g. values concerning food and survival) and with values concerning man's relationship to himself (his self-development). These are not excluded from sociological conceptualizations, such as that of Parsons, but they would need be seen in the perspective of their relation to society. The functionalist approach may not only lead to a somewhat narrower focus, it may also lead to a rather conservative perspective on values--if they perform necessary functions, major change may be a threat to society. Oran Young has commented on this:[6]

> Much of structural-functional analysis tends to focus primarily on essentially static relationships rather than on dynamics. The approach is concerned, above all, with the problems of systemic survival, the requirements of stable adaptation, and the operation of various functions and structures oriented toward system maintenance.

Although Young goes on to deny that a "status quo" bias is inherent in the approach he does not deny that most practitioners in the field have de-emphasized system change.

A related problem is that human values come to be conceptualized not as elements which control the system, but as elements which, for the sake of stability, the system controls. The functionalist tradition does allow many sets of values and institutions to serve the necessary assumptions, but assumes that socialization can act to maintain a healthy society and that values are highly flexible. Amitai Etzioni illustrates the difficulty when he observes:[7]

> The central point at which the prevailing theories of social action of both the Meadian and Parsonian traditions differ from both the Marxist and the Weberian perspectives is that the former assume, in effect, that human needs are almost completely pliable within very broad limits set primarily by physiological tolerance, such as the need for heat, sleep and food. Social needs--e.g. for affection--are recognized by these theories, but it is emphasized that such needs may be satisfied by a large variety of institutional arrangements..... it is assumed, in principle, that there are very few if any limits to socialization and social control. The best indication of this assumption is the presence in these theories of conceptions of deviant individuals, sub-cultures, and even social movements, but never of a deviant society.

Etzioni goes on to suggest that societies do differentially satisfy basic human needs. Interestingly, however, he too narrows his focus from all human needs, including the physiological, to a list of needs that are satisfied in the social arena: affection, context, repeated gratification, stability, variance in a social structure (i.e. variance in roles and statuses corresponding to variation in human personalities and capabilities).[8] Much of the discipline of sociology has thus focused on man in the social context, rather than physiological, psychological, or political man, to the point where it may be impossible to gain an overall perspective on human values. Another illustration of this narrowing in focus and its implications in terms of the values stressed can be seen in the relative absence of discussion of largely individualistic values such as freedom, privacy, and as the psychologists would say, "self-actualization."

Exceptions to this narrowed focus may be the approaches in sociology which are not based in a functional tradition, nor perhaps any other theoretical tradition, but which seek to describe human value systems. For instance, Pitirim Sorokin has outlined and extensively documented three major "logically integrated cultures." Two of these are profoundly different. For members of the Ideational culture, reality is hidden and what they sense is illusory. Reality lies instead in God, Nirvana, or some other spiritual concept. The needs of individuals are mainly spiritual and "the method of their fulfillment or realization is self-imposed minimization or elimination of most of the physical needs."[9] In contrast, in the Sensate culture reality is what the senses say it is, needs and aims are primarily physical, and the method of attaining them is "modification or exploitation of the external world." The third logically integrated culture is a mixed form, the Idealistic. Sorokin, as Etzioni suggested of Mead and Parsons, also stresses the pliability of man within very broad limits, presumably even across what we might consider basic human values concerning survival.

Sorokin's approach is far from operationalization, but it does provide some interesting perspectives on cultural differences in values. Moreover, he provides in his contrast of the cultural types a checklist of four items on which cultures vary:

1. The nature of reality.
2. The nature of the needs and ends to be satisfied.
3. The extent to which these needs are to be satisfied.
4. The methods of satisfaction.

This discussion of the sociological literature should not end on a note which deprecates the potential contribution to our study of values from what may be the mainstream of the discipline--the functionalist tradition. The focus of this project, on formal governmental policy output, could lead us to be too hasty in dealing with the sociological perspective. Much important "decision-making" goes on outside of formal structures, and the implications of this for the Mesarovic-Pestel world model should not be ignored. Nor should we ignore the fact that the model has no representation of the social system in which those decisions are taken. There is a major hole in the model--rather than saying that a literature which deals with that hole is of little or no concern to us, we might well ask if we need fill the hole.

B. Psychology

Among psychologists, as among sociologists, there are both those who seek basic needs or functions and thus can shed light upon values, and those who attack values directly and more descriptively. Among psychologists who look at basic human needs, Abraham Maslow and the list he developed are probably best known. Maslow says that all humans have the following need hierarchy:[10]

1. Physiological
2. Safety
3. Belongingness and Love
4. Esteem
5. Self-actualization

In addition to Maslow, lists of human needs or need hierarchies have been drawn up by Karl Mannheim, Vilfredo Pareto, Talcott Parsons, W. I. Thomas, Max Weber, Florian Znaniechi, Nicholas Rescher, and undoubtedly many others.[11] Although there is often much in common among the lists, each writer has presumably thought his list different enough, and sufficiently better, to merit development. This has led to some skepticism regarding the entire effort:[12]

> Nobody has ever been able to formulate an inventory of original or unsocialized tendencies that has commanded more than scattered and temporary agreement. In the second place, the very meaning of 'original human nature,' in any other sense than a range of possibilities, each of them dependent upon specific experiences for its development or maturation, has always proved exceedingly elusive and obscure.

Quite probably Sorokin would agree with this--the major differences among his culture types suggest an almost impossible task of defining human nature or needs--Sorokin might well classify Maslow as a representative of the Western Sensate culture, unable to see that in other cultures, other rank orderings in the hierarchy, or indeed, other listings would be necessary. In fact, Maslow does have difficulty in coming up with an explanation as to why people would adhere to Sorokins' Ideational value complex. He has a partial response:[13]

> Perhaps more important than all these exceptions [to his hierarchy] are the ones that involve ideals, high social standards, high values, and the like. With such values people become martyrs; they will give up everything for the sake of a particular ideal, or value. These people may be understood, at least in part, by reference to one basic concept (or hypothesis), which may be called increased frustration-tolerance through early gratification. People who have been satisfied in their basic needs throughout their lives, particularly in their earlier years, seem to develop exceptional power to withstand present or future thwarting of these needs simply because they have strong, healthy character structure as a result of basic satisfaction.

Sorokin is not, however, talking of people who have in some way been deprived by their environment after a considerable period of satisfaction--he is talking of individuals and even entire cultures who seem willing to deprive themselves of what for Maslow are basic physiological and safety needs.

Perhaps, however, there need be no conflict here at all. To begin with, entire cultures do not deny themselves survival needs. If they did, such cultures would be short-lived. Some cultures do have a higher number of people who in a given situation will sacrifice their lives for perceived higher "ideals," and who will at other times exist with the bare minimum of food and shelter. These exceptions do not necessarily, however, deny the general principal involved in Maslow's hierarchy. Instead they suggest that people might be satisfied (because of their culture and socialization) at different levels on these need or basic value dimensions--in Maslow's term, they achieve "peak experiences" at different levels. It may be possible to explain aesthetics, if not martyrs. We will return to some of these issues later.

There is in psychology and social psychology another literature of interest to us. In contrast to the above theoretical and deductive approach to values (although it clearly does have empirical content), the other approach is specifically descriptive and inductive. There is in psychology a phlethora of studies on attitudes.[14] Typically, attitudes are said to consist of three components: the affective, the cognitive, and the behavioral. Relations among these components have been empirically found to be close, but imperfect. When one component changes and dissonance increases, mechanisms of change in all three components act to decrease dissonance.[15]

There is to my knowledge no effort in this literature to categorize and study the affective or value component of attitudes across complete societies. For this we might have to rely on works in the functional tradition. The attitude studies can be of major importance to us, however, because of their focus on the relationship among the three components. Some (by no means all) of the inter-cultural differences suggested by Sorokin may, in fact, be explained by the close interrelationship. If societies are unable to provide more than survival levels of certain value objects, the affective value placed on levels of that object may adjust accordingly, and over very long periods entire world views may adapt. This notion is encapsulated in the slogan, "Religion is the opiate of the masses."

C. Philosophy of Values.

I am using "philosophy" very generally here to incorporate those who write on values and value change without a clear disciplinary tie. That is, the original focus of those discussed in this section is values. This category includes some of the work which most clearly delineates value concepts and change processes. For instance, Nicholas Rescher has sought to clarify the concept of value.[16] He has defined value in a very action oriented, goal oriented way: "A value represents a slogan capable of providing for the rationalization of action by encapsulating a positive attitude toward a purportedly beneficial state of affairs."[17] Based on this definition, he provides several dimensions of values, including:

1. The type of object with the desireable or value characteristics. Categories on this dimension include thing values, environmental values, individual or personal values, group values and societal values.

2. The type of benefits obtained from realization of values. Rescher's categorization here is like those of human needs: material and physical, economic, moral, social, political, aesthetic, religious (spiritual), intellectual, professional, and sentimental.

3. The potential beneficiaries of value realization; on a dimension from the value-subscriber himself through other individuals and groups to all of mankind.

4. The super- and sub-ordination of values to each other. Some values may be "instrumental," such as frugality or generosity.

This kind of dimension building and category formation can be very useful in our own conceptualization of values. Particularly useful may be the distinction between benefits and type of object. This suggests a potential bridge from basic human needs (benefits) to specific goals (generally object oriented) concerning the system. The possibility of such a bridge will be discussed later.

Rescher has also developed what he calls a preliminary typology of value change modes.[18] Types of value change are listed as value subscription (essentially no change), value acquisition and abandonment, value redistribution, value emphasis and de-emphasis, value rescaling, value redeployment, value restandardization, and value implementation retargeting. All of these involve value upgrading or value downgrading. Mechanisms of value change include a change of information, ideological and political change (indoctrination), boredom, disillusionment and reaction, economic-technological change, and change in demographic factors. Rescher suggests in general a cost-benefit approach to value maintenance and change. When it is time to develop specific procedures for operationalizing value change, Rescher's analysis should be given considerable attention.[19]

There is a project of relevance to the study of value change which does not fit well into the category of philosophy, but which fits even more poorly elsewhere. This is the project at Harvard University directed by Emmanuel Mesthane to study the impact of technology on society. Part of the fourth annual report discusses the literature and issues involved in the study of "Technology and Values."[20] Although the focus on technological interaction with values may seem narrow, the report is not.

Another orientation in the philosophic work has value for us. This is the philosophic effort to understand philosophies of value, which can give us a better insight into value frameworks suggested by others and into how our own value perspectives might influence our work. A fascinating comparative study of prescriptive political theories has been done by John Breckling.[21] This is of interest to us because prescriptive political theory is explicitly value theory. Breckling suggests that all prescriptive political theory can be conceptualized as models built upon the following assumptions:

1. The nature of the material environment.
2. The nature of man.
3. The relation of man and environment.

4. The nature of society.

5. A present social state or condition.

Upon this base, prescriptive political theory postulates goals for individual man and for society.

Breckling's analysis finds, among much else, that assumptions about the nature of the material environment are a basic distinction between writers within the liberal and Marxian paradigms on the one hand, and those of the classical and what Breckling calls the neo-scarcity model, on the other hand. Both the former schools assume an essentially unlimited environment which man is capable of exploiting, while the classical school and the neo-scarcity school both reject the notion of unlimited exploitation.

The major impact of this basic assumption on entire philosophies should be salient for us on two bases. First, the Mesarovic-Pestel World Model has at least a strong tendency to be neo-scarcity in its assumptions, and its creators quite openly subscribe to such a model. This will inevitably affect the goals for man as an individual and for society which are suggested from the model analysis. Second, as we are developing a simulation of the norms stratum, we should recognize that various decision-makers and even cultures will differ in such a basic assumption, and that this difference will affect their values and goals quite generally. The Liberal and Marxian paradigms are wide-spread, but not universal.

A second fascinating analysis, this time of specifically the kinds of value theories discussed in this chapter, was done by Walter Weisskopf (an economist) of papers delivered at the 1957 M.I.T. Conference on "New Knowledge in Human Values."[22] Weisskopf sees

> three different avenues of approach to values in modern thought....they are based on three different models of thought or images of man which can be called the naturalist, the humanist, and the ontological approach. These three models differ in their methods of acquiring knowledge and in their concepts of reality.

The naturalist, says Weisskopf, has an image of reality limited to that perceived by the five senses. Inner experiences, emotion, and other mental abstracts "require factual verification by the senses in order to be acknowledged as real." The humanist takes a more holistic approach, relying also on inner experiences. The ontological perspective seeks to transcend the facts of both sensory observation and of intuitive experience, and derive "its image of man from the analysis of being as such. ."

Whether or not one accepts and finds useful these particular categories, the actual analysis by Weisskopf of values approaches is very insightful. He finds, for instance, an implicit value placed by many if not most conference participants on survival--it becomes a testing point for the quality of other values, especially among the naturalists. Ideas centering on mental health tend to distinguish humanists from naturalists. For instance, Maslow enhances self-actualization and looks for evidence in the choices of "healthy people." Weisskopf points out the obvious, however--that some clear values are involved in determining who is mentally healthy. Why, he asks,[23]

> are such generally recognized virtues as kindness, love, unselfishness the result of self-actualization and why does Maslow exclude such obvious phenomena of 'self-realization' as agression, destruction, hostility, domination, egotism?

Weisskopf also points out the potential conflict between largely individual values, such as those emphasized by Maslow and other psychologists, and the more social values.

From the ontologists, including Weisskopf himself, comes an almost radically different picture of values. Values are derived from the essence of man's being, and reflect man's desire to unify a basic split in human existence, between man's being and his consciousness of that being. According to Weisskopf, that striving leads in the best case to a search for individualization which is not too different from Maslow's self-actualization. This belief that values are rooted in man's essence leads to the conclusion that "moral law is man's ...essential nature appearing as commanding authority."[24] Such laws appear as external imperatives only because man is in an estranged state of existence. Thus Weisskopf and Paul Tillich reject the derivation of values from what Tillich calls "The arbitrary ordinances of a transcendent tyrant," as well as values "determined by utilitarian calculations or group conventions."

On the whole, Weisskopf's discussion should not be rejected as "merely" philosophic commentary--it goes to the heart of questions about the origins of value systems and the nature of those systems.

D. Social Indicators

Although there have been some exceptions, particularly in psychology, the literature we have discussed up to this point has been largely theoretical--concerned especially with the factors within man or his social institutions which give rise to values. There has been relatively little attempt to become specific about what man values. In terms of Rescher's dimensions, we have been focusing on the type of benefits humans reap when their values are realized, but not on the type of object with the desireable characteristics. This latter focus might well define the purpose of the social indicators and quality of life literatures.

The division between this section and previous ones in the chapter may have its basis in the policy orientation of those working on social indicators. Theirs has been a desire to not wait until some full-blown deductive theory emerged from the traditional disciplinary work, but to produce something useable immediately. Their argument has been that critical problems deserve immediate attention and that their work could also assist the development of more general and highly structured value theories.

As useful as the social indicators developed in this movement may be, some of the basic difficulties of such an inductive approach remain to be solved.

First is the question of comprehensiveness. On what basis does one decide he has indicators of all that is considered valuable? Another problem is the evaluation of the state of the environment in terms of the indicators--how does one assure that the evaluation is in terms of societal values (if that is what one wants to assure) and not the values of the indicator developer? The same question can be asked also of the set of indicators developed and ties to the comprehensiveness issue. A third issue is somewhat more methodological. How does one translate the indicators into policy recommendations? Part of this is a question of indicator "weighting." If some indicators are interrelated, and measureing the same "value," then whether one has 1 or 2 or 10 such indicators might determine how bad a situation looked and what priorities were suggested (unless some formal weighting procedure were developed). Another part of the translation to policy problem is that it requires a relatively good understanding of the environment in which policies are to work, unless one is satisfied with an experimental approach and one which may cure the symptom (fix the indicator) but leave the problem. Still a fourth problem, and one relevant to the World Model project, is the essentially culture-based nature of the indicators. As a result of their development in Western industrialized countries, especially the U.S., they are oriented towards problems of those societies. Such problems tend to fall overwhelmingly in categories of social relations and self-actualization, not in the physical survival and safety categories relevant to less developed countries.

This is not an admonition to social indicators scholars to go back into traditional discipline frameworks--that might well hurt much more than help. It is simply a statement of such problems as remain yet to be solved--problems towards which scholars in the area are directing their attention. For instance, the difficulty of working without a more general and exhaustive set of categories has been well recognized and documented. In 1965, Bertram Gross asked, "Wouldn't it first be necessary to develop an ordered set of concepts on which social indicators could be based?"[26]

Since that time a number of studies have moved in this direction. The Rand Corporation did a study in which subjects (college students) were asked to suggest the interrelationship among 48 categories formed from about 250 items related to the quality of life.[27] A pair comparison method was used with the following acceptable responses:

4 Practically the same
3 Closely related
2 Moderately related
1 Slightly related
0 Unrelated

On the data of this test a cluster analysis was done and thirteen clusters of quality of life indicators were developed. These clusters were then given names and ranked in order of relative importance by the respondents. The results were the following factors:

1. Love
2. Self-respect
3. Peace of mind
4. Sex
5. Challenge
6. Social acceptance
7. Achievement
8. Individuality
9. Involvement
10. Comfort
11. Novelty
12. Dominance
13. Privacy

Again note that none of these deal with food, shelter, or other basic needs--the closest may be comfort, but that is clearly tapping more of a luxury dimension. Thus these factors are more important in telling us something about individually achievable values in an affluent Western society than in giving us priority listings for societies across a broad range of economic development.

A second study which has sought to create order from the extensive listings of social indicators is the Stanford Research Institute's Toward Master Social Indicators[28]. They presented a hierarchical heuristic scheme for social indicator classification. They sought further to develop a scheme to evaluate progress in their categories, so as to indicate major problem areas. This was done by suggesting that each element on each layer in their hierarchy have a goal-specification and an attainment-measure scale (minimum, standard, and optimum levels). The first level on their hierarchy is a single category, "The general good." Below that are two categories of overall quality assessment, one for society and one for the individual. Each of these is then tentatively divided into categories based on a draft of the HEW Social Report.[29] These categories are health, opportunity, environment, standards of living, public safety, learning, science and culture, and democratic values. Within each category they suggested indicators of each attainment level, again based on the Social Report.

The SRI study thus stands as a major step towards a more systematic rendering of social indicators. Their effort in their own words was directed towards three problems:[30]

1. Appropriate attainment level categories must be devised for each of the indicator areas identified in the Social Report.

2. An approach must be found to assessing where the nation as a whole, and segments of it, stand in the attainment spectrum in each indicator area.

3. A way must be found to interpret attainments in the various areas in terms of some overall quality measure; to do this entails making quality-of-life assessments comparable (or at least weighted) across the indicator areas.

They have clearly made some progress in all of these areas. There are at least three fairly major problems not yet resolved, however. First, are the categories of the Social Report adequate? Are they comprehensive and largely "orthogonal"? We have already suggested that indicator restricted to social and individual values might be inadequate for indicating the problems of less economically developed societies--the inclusion of health and standard of living categories in part resolves this issue. (It is interesting that the Rand study derived no health category--perhaps college students are much less concerned about this than the general public.) The second problem is change in goals and relative satisfaction with the level of category attainment. For longer run use, mechanisms of goal change are a necessary addition to the SRI approach--for instance, judgment of attainment level will invariably shift upward with the movement of societies or individuals along any objective scale. What seemed "optimum" at one time may be only "standard" or even "minimum" as we actually approach the original "optimum" levels. The third major problem is the need for understanding of the social (and individual) systems so that the problems discovered with the indicators can be translated directly to policy recommendations. This is very clearly recognized by the SRI and they call for a "Comprehensive Social Data System" which would include math model building and predictive accounting.

The approach to be suggested later in this report builds on the ideas of the SRI study and attempts to resolve some of the still outstanding issues.

E. Empirical Studies

The final class of literature to be mentioned in this report consists of potential data sources. These are materials that lack any real theoretical or even inductively created structure.

The Human Relations Area Files (HRAF) classify and abstract materials concerning ethnic groupings (nations) around the globe. These materials touch on every aspect of the lives involved, including values. One major category of the system is "norms," with an admonition to also look at "attitudes," "ethical ideals," and "legal norms." A second useful category for us would be "cultural goals." The description of this category suggests we look also at more specific substantive areas like "population policy" and "savings and investment." This sort of data base should be exploited.

A second potentially useful data source is Hadley Cantril's studies on The Pattern of Human Concerns[31] Through open-ended questioning on major areas of hope and concern for the future, Cantril discovered much about such hopes and fears in some developed Western countries (the U.S. and West Germany), in some communist countries (Poland and Yugoslavia), and a number of LDCs (Nigeria, India, Brazil, Egypt, Cuba, the Dominican Republic, the Philippines, and Panama). As the title of the study suggests, he sought and found many common themes throughout these diverse systems. For instance, and not surprisingly, health of self and family was a dominant concern everywhere.

Cantril also sought to discover satisfaction of individuals with their lot and expectations of future satisfaction. For this he employed a "self-anchoring striving scale." He asked respondents to place themselves on a 10 point scale which ranged from the worst situation imaginable to the best. This is self-anchoring because there is no objective scale of conditions underlying it--what constitutes best, worst, and present situation is subjective and individual. With this scale Cantril discovered some interesting phenomena. One is the general tendency throughout the world to place one's present condition near the center of the scale--only slightly above for the affluent societies and only slightly below (except for the Dominican Republic) in most underdeveloped countries. A second interesting phenomenon lies in the expectations for change in the future. Looking forward five years, most respondents, especially in the LDCs saw great improvement in conditions. Looking back five years, they also reported some improvement in conditions, but not as much as expected from the future. These and other discoveries about subjective satisfaction with various conditions might be quite helpful for our study.

Other data for the study lie in various world indicator sets. For instance, Charles Tyalor and Michael Hudson's World Handbook of Political and Social Indicators [32] can provide objective indicators of conditions.

3. General Comments on Values and Operational Norms

This chapter will seek to lay out some basic conceptualizations for the Project UTOPIA. These are necessary for the discussions to follow. Those latter discussions, however, will be the ones to develop very specific and operational definitions. More importantly, since definitions are never incorrect, only more or less useful, those latter discussions should also show the utility of the definitions.

A. Terminology

It has been stated that[33]

> Values and norms...are terms of unusable vagueness today not because they cannot be usefully defined, but because they have not yet been sufficiently analyzed, although an abundant store of accesible fact is available for the purpose.

The important point here is that the terms should be "usefully defined"--the utility of definitions is the only criterion by which they can be judged. Thus we will try to present here definitions that will allow operationalization and use later in this paper--compatibility with earlier definitional approaches will provide only a secondary criterion.

By "values" we will mean the most general and unchanging dimensions of human affect, similar to and probably derived from human needs. These will be, in Rescher's terms, categories on a type of object dimension--that is, there will be an object or set of objects (abstract or concrete) in relation to which the value is defined. The term "human needs" will be reserved for classifications such as those of Maslow and Rescher of human drives--in Rescher's terminology again, the kinds of benefits to be derived from the realization of particular values. Values are basic and unchanging, like human needs. A value may become less salient, or be "down-graded" because of its relative satisfaction, but it never disappears.

Values become more concrete through their translation into operational norms. Operational norms, unlike values, are directly related to some objective scale or indicator. They are in essence the operational translation of values. Various operational norm scales may be related to a basic value and more or less clearly reflect it. Thus if shelter were a basic value, a scale of how many rooms per person a dwelling had would be one operational norm scale; an indicator of square meters per capita would be another; a measure of heating system quality still another. Whereas values tap relatively distinct dimensions of values (are basically orthogonal), the operational norms are like clusters of variables loading heavily on these basic and orthogonal factors.

The relation of the operational norms to the objective scale is complex. The operational norm is essentially an evaluation of the levels upon that scale. That evaluation can, of course, change over time and with circumstances. A "goal" is thus one type of operational norm--it translates into value terms one level on the scale. Expressions of satisfaction or dissatisfaction with various levels constitute another type of operational norm. These operational norms may change, but the basic underlying value continues to exist.

The conceptual approach is somewhat like that of the Stanford Research Institute (SRI) with their expression of goals and attainment level measures for various indicators. The place of attainment level in their scheme is, however a little ambiguous because of the failure to clearly separate the objective and affective scales on the operational norm level. Attainment levels are derived from goals, and thus supposedly represent the affective element. But they are translated into objective indicators. This is unfortunate for two reasons. First most of the objective indicators suggested for each attainment level actually cut across all levels of attainment, and thus the motivation for their separation is not at all clear. Second, the direct translation of an operational norm like attainment levels into objective indicators "freezes" the attainment level.

As noted above, the affective element or operational norm will change with time and circumstances. Had the SRI made a clear distinction between objective indicators and subjective operational norms in association with those indicators, their approach would be more attractive.

B. Possible Basic Value Sets

Table 3.1 shows one possible set of basic values. The lef-most column identifies the three systems within which the needs are defined. The first is the biological system, the second the social system, and the third the "mental system" or ego.[34] In the central column are universal human needs as laid out by Abraham Maslow. These fall reasonably clearly into the domain of the three systems. They are not really an adequate statement in themselves of basic values because they are general benefit oriented and not object oriented. The basic value list in the third column of Table 3.1 suggests some essentially need-derived object-oriented basic values. The decision to focus on object-oriented basic values is a purely pragmatic one. Before either societal or individual decisions can be made in any effort to achieve a value, some relatively concrete target must be available. This is especially clear at the biological system level with survival and safety needs. These must be translated into food, shelter, and so on, so that the particular object of the value can be sought. In the case of the higher level needs this is less true. There is no clear target object of belongingness and love needs. Yet the existence of families and of non-family social groupings can be a target object of a political system seeking to maximize the likelihood of such need satisfaction. Similarly, a formal education system and opportunities for self-improvement (cultural facilities, travel possibility, etc.) can provide a millieu encouraging self-actualization.

Self-esteem needs lie at the intersection of the social and ego systems. They are essentially an other-directed phenomenon, with the self-image being

TABLE 3.1 A BASIC VALUE SET

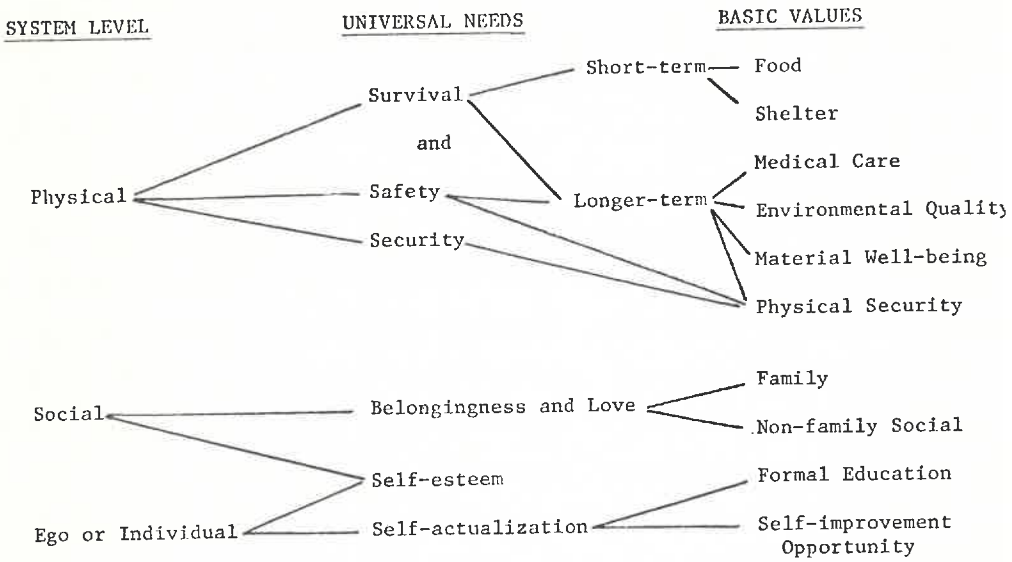
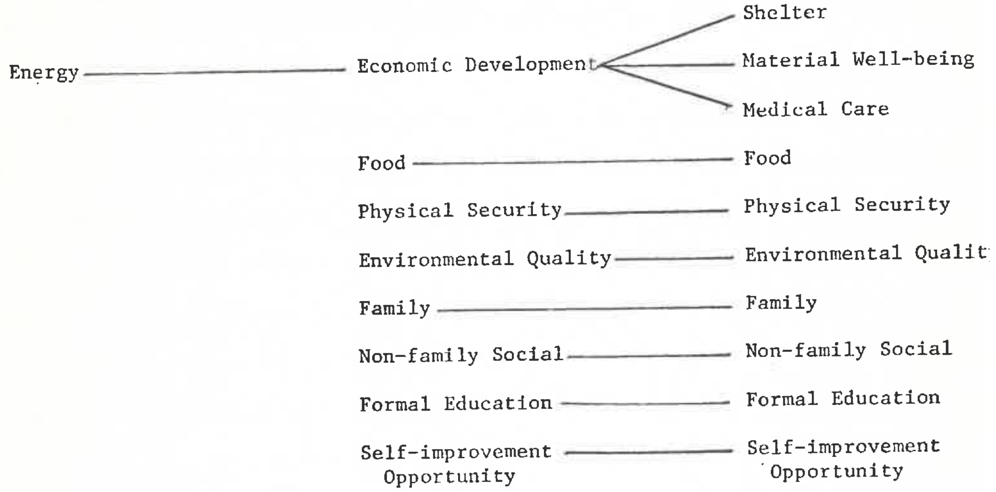


TABLE 3.2 ALTERNATIVE BASIC VALUE SETS



derived from the images of others (this contrasts with self-actualization which is entirely an ego oriented phenomenon). Thus opportunities for self-esteem can be maximized by increasing either societal approval, perception of such approval, or both. It is not clear what social structures or institutions can do this. It is tempting to say that a more egalitarian and barrierfree society would best assist those whose esteem is low because they are the target of less disapproval and prejudice. But those same barriers have in large part established high levels of self-esteem for those on the "right" side of them. In general, self-esteem might best be treated not as an independent need, but as a combination of belongingness and love needs and of self-actualization needs. Thus no related basic values have been identified in Table 3.1.

It should be stressed that the relationships between universal needs and basic values is not perfect. There are, in fact, usually several needs connected with each value. In the case of food, survival is the need at low food levels. As food consumption increases, it becomes increasingly clear that other needs are being satisfied, including such socially derivative ones as self-esteem. Eventually, further consumption of food may actually threaten survival.

The values in Table 3.1 form something of a hierarchy, corresponding to the hierarchical structure of Maslow's needs. This does not mean that there is an easy translation into policy choice--for instance, it does not mean that individuals and societies will first act to satisfy the top need or value, then act on the second, and so on down the list. As Maslow says:[35]

> In actual fact, most members of our society who are normal are partially satisfied in all their basic needs and partially unsatisfied in all their basic needs at the same time. A more realistic description of the hierarchy would be in terms of decreasing percentages of satisfaction as we go up the hierarchy of prepotency. For instance, if I may assign arbitrary figures for the sake of illustration, it is as if the average citizen is satisfied perhaps 85% in his physiological needs, 70% in his safety needs, 50% in his love needs, 40% in his self-esteem needs, and 10% in his self-actualization needs.

Table 3.2 presents an alternative list of basic values. The premise of the alternative list is that shelter, material well-being, and medical care are almost entirely dependent on economic development. Thus a value on the economy alone could serve as a surrogate for those three values. Food cannot so easily be guaranteed by economic development since population and land quantity and quality are also factors. Similarly, physical insecurity (e.g. crime) can be greater in more developed than in less developed countries, as can the deterioration of the environment. This alternative list, at least at the biological system level, could serve the Mesarovic-Pestel World Model. That model has no representation of social or ego system variables, so values at those levels, cannot be meaningfully handled. Energy is shown in Table 3.2 not as a separate value, but important because of its relation to the economy. If the economic target value is used, and the relationships between energy and the economy are properly represented in the model, energy need not be treated as a separate value.

Further development of these values, through the specification of operational norms, mechanisms for norm change, and the procedures by which values control policy-making, will follow in subsequent chapters.

C. Whose Values?

Since the purpose of Project UTOPIA is to represent operational norms that guide decision-making, it is appropriate to ask exactly whose values this implies. It would be theoretically possible to simulate the various different value systems brought into the policy process by conflicting political forces, and to simulate the emergence from that conflict of the final value set represented in policy. Su an approach is in practice impossible. The undertaking would be hopelessly comple for a broad range of issues in even one nation. As an approach for 10 regions of nations, as in the M-P World Model, it has absolutely no hope of success. Instead, we must seek to represent the end result of the political process--that abstract set of values which will guide policy-making.

In a relatively homogeneous and democratic society and region, that represents no problem. When the government is less representative, some mix of decision-maker and public values is needed. As Amitai Etzioni said,[36]

> Elites, even relatively responsive ones, seem routinely to reveal a double standard in their decision-making, taking into account both societal and elite needs.

When there are two or more strong and distinct values systems and each appears to have a chance at the direction of government (through revolution or election), it might be wise to represent both and to see the difference in impact.

4. Operational Norm Establishment and Change

The basic value dimensions suggested in the last chapter are open to question and substitution. They need not be firmly established before we move to the next question--the establishment of operational norms (including the selection of their related objective scales) and their change. Because of the relation to the objective indicator level, operational norms may pose even more of a problem than values. Whereas the basic value list could be in some sense derived from human needs, operational norms such as goals cannot be in turn derived only from values--operational norms are a function both of the values to which they are related and of the objective situation of the indicator to which they are related. Some very complex psychological processes are involved. For instance, the process of cognitive dissonance reduction causes us to shape our affective evaluation of levels on an indicator to what we perceive as possible to achieve on that indicator. It is not reasonable to expect that we can lay out all of the mental processes involved, especially since we are dealing with aggregations of individuals and not with single persons. Instead we must seek some surrogate summary procedure.

There are essentially two general approaches that we could take to the establishment and change of operational norms. The first is deductive. We could try to derive operational norms from general values and/or the state of the environment, and to change them according to similarly deductive principles. Second, we could largely or entirely ignore the general value level, focus directly on the operational norms, and if necessary, construct a more general structure in an inductive fashion from the operational norm layer. There are, of course, also mixed strategies, and we will suggest one in the next chapter. For the purposes of this chapter we will maintain the division and discuss the range of possibilities.

A. General Value Deductive Approaches

It might seem straightforward to set and change operational norm values (e.g. goals) on the basis of a general value list like that in the last chapter, or on the basis of a human needs list. The general principle could be straightforward--as one need is satisfied, the next would become relevant or salient. The problems with such an approach should, however, be obvious. First, as the earlier quote by Maslow suggests, there is no complete satisfaction or satiation before the next higher value in the hierarchy becomes the focus. Second, and related, the interaction with environmental constraints is considerable and they must be involved in the establishment and change processes.

One basically deductive approach has been developed by Bossel and Hughes.[37] It builds upon a different conceptualization of values than that outlined earlier. It posits general values which again are object values, not related to a particular objective scale (i.e. not operational norms). But the general values do vary--specifically, they vary along an 8-point subjective scale ranging from zero or extremely low to extremely high. Their variance is a function of "monitor variables", that is variables in the general system which are monitored by the decision-makers and can be expected to change their values. The mechanism for change is an influence matrix which relates each monitor variable to each general value with the same subjective 8-point scale from zero to extremely high on which the general values vary. The values are also interrelated, so that a change in one affects others, again through an influence matrix. A finite difference summation determines the new levels of the values when changes occur in the monitor variables. At the operational norms level, goals are established on an objective scale. These are also changed by an influence matrix using finite difference summation. The influence matrices for a prototype model were derived from questionnaires.

This approach has many of the desired features for a policy directive normativ representation. It does lead to specific goals at the operational level. It does consciously incorporate the environmental impact on values. The approach also has some weaknesses which should be noted. First, the entire procedure is quite complex and involves multiple subjective judgments. Difficulty and complexity in themselves are not criticisms since no reasonable approach is likely to be simple. But the monitor variables are measured in different units, which means that a judgment about the significance of a change is necessary (e.g. high, medium, low). Then the two influence matrices must be created. Initial levels for values and goals must be established. Goals are again on different objective scales so that some judgments about degree of change with influence matrix impact must be made. The chances for errors, which might compound themselves in time, are many. A second problem is that the values must be orthogonal for the approach to work. If they are not, then the use of the influence matrix to change goals will "weight" some values more than others. Again, this is not a fatal criticism of the approach--the orthogonality issue is one which creates problems for any approach, and we shall return to it. A third problem is that goals must be weighted besides being set initially. Because the operational norm objective scales are not in common units, distance from the present or projected value and the goal is not in itself an indication of how dissatisfied one is with the value and how desirous of change one might be. Instead, weightings of some sort are necessary. No really adequate weightin system has been developed with the approach. Finally, the procedures for value and goal change described above do not handle all value-goal changes needed. They move values and goals in a direction which given the changes in monitor variables would be optimal. But there are constraints in the environment on what can be done. If goals are changed unreasonably, cognitive dissonance would develop, goals would be "compromised," and eventually the superior values themselves would be affected. Goal adaptation to the environment has been added to the approach for this reason.

All in all, this type of deductive approach does offer one way of handling the norms simulation. The problems are significant but not necessarily insurmountable. Greatest are the weighting issues and the rather large number and complexity of the subjective elements.

Another potential approach to UTOPIA involves the creation of a single "quality of life" indicator in which various value objects are represented as components of changing importance. Figure 4.1 suggests how this might be done. Although this representation might appear useful, especially since it shows the changing importance or weights of the values with relative fulfillment, it is less an "approach" than a set of problems. Such components would need be derived from and then again translated into objective scales of some sort. The questions of what values to include and what objective indicators to relate to them remain to be answered.

A very similar approach would be to create a "comb" of values as in Figure 4.2. The comb indicates some sort of hierarchy in values. Presumably a decision-maker would seek to move up his achievement levels on objective variables associated with these values in a manner reflecting the relative weight. Again, the approach without further development does nothing to identify values or operational norm scales. Moreover, it does not touch the very central issue of the association of operational norms with objective scales. The comb could consist of objective scales and be created with the length of the teeth representing relative importance--in other words, be built at the operational norm level. The key question then becomes, how can the relative teeth length or value weightings be obtained?

Some of the more inductive approaches to operational norm representation discussed below will bring out the kinds of additions to any deductive approach which must be made before they can be useful. After that discussion, the next chapter will present in detail a combination of deductive and inductive approaches which overcomes most of the problems.

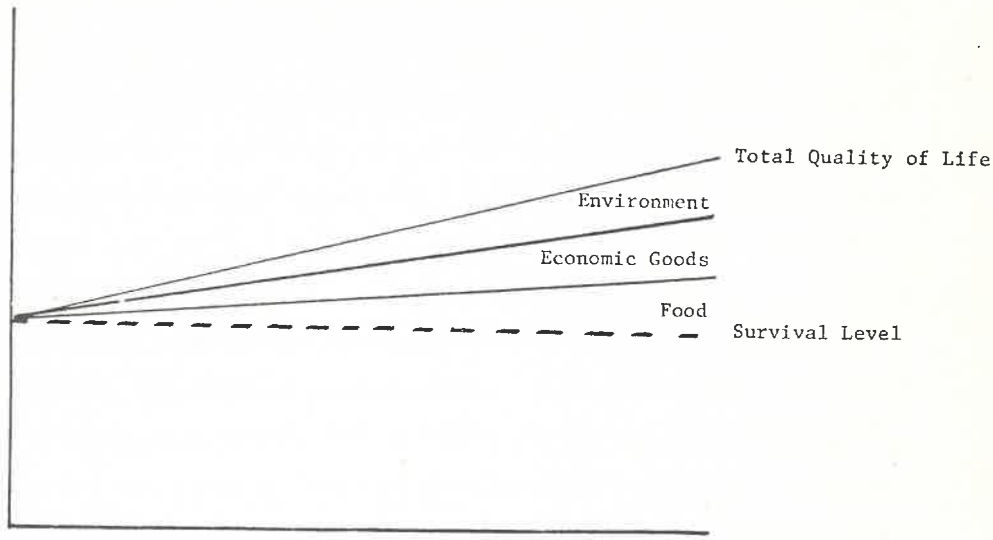
B. Inductive Approaches

One general advantage of inductive approaches is flexibility--as the causal stratum or basic system to which they are applied changes, they can be adapted fairly easily--the deductive approaches may require significant revision in general value sets and linkage mechanisms (such as the influence matrices). Moreover, the normative structure itself can be changed more easily. This can be an important advantage if we want to allow interactive setting of values. A disadvantage is that they frequently handle operational norm change less straightforwardly, if at all. A second is that they provide no basis for the focus on any particular set of operational norm objective scales.

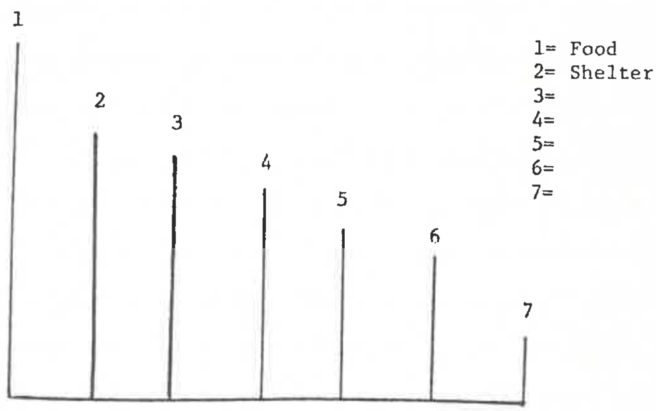
Perhaps the most extreme approach would be to focus on longevity as the ultimate value and act to maximize it. Many values, including all biological ones, translate easily into the desire for a longer life. It could also be argued that the satisfaction of social and individual values contributes to a longer life, and they would thus be represented in the approach. The unacceptability of longevity as the ultimate value is, of course, are major problem. A second is that the model upon which the approach was applied would need restructuring--all processes in it would need be analyzed for their contribution to longevity, a probably impossible task.

More realistic approaches involve multi-values at the operational goal level. Basic to all of them is the need to associate an operational goal of some form with an objective scale. This has to be done in a way which tells us which values the decision-maker will devote attention to at any one time and in a way which allows trade-offs among the values when environmental constraints do not permit the optimal solution (always the case).

FIGURE 4.1: QUALITY OF LIFE INDICATOR



GURE 4.2: COMB OF VALUES



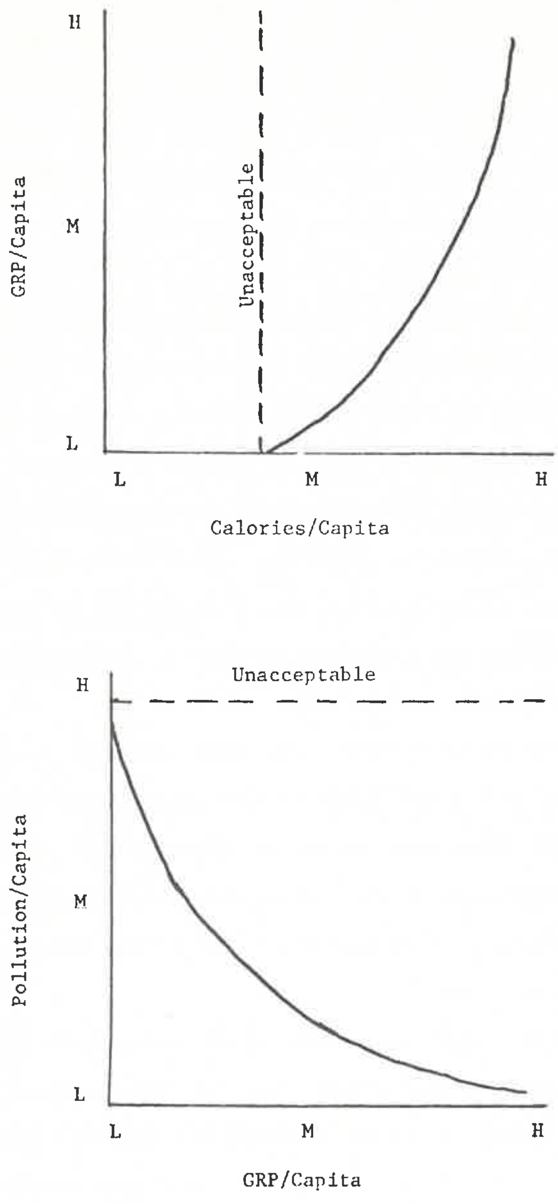
Perhaps the most direct approach to these requirements would be the establishment of trade-off curves among all operational indicators. Figure 4.3 suggests the general form of this type of operational norm. The curves show a path which the value holder would like to see folowed in the joint provision (or reduction) of two value objects.[38] A small but important addition to these curves might be an indication of an "unacceptable" level of each operational indicator as a result of immediate threat to survival. Trading below that level would not occur.

Attributes of trade-off curves include their openness to examination and criticism. In interactive use a model user could even draw such curves with a light pen and have his values recorded for him. The changing nature of the trade-offs with relative satisfaction of values is especially well captured in this approach. Weighting of values is implicit in the approach. At any point on the objective scales, the trade-off curves tell us the relative importance or weight of an additional unit (no matter what scale of measurement) of each item in relation to all other items.

Problems facing the development and use of trade-off curves include those facing all inductive approaches--the lack of criteria for objective scale inclusion or exclusion and the problems of handling value change. Actually the value change issue is in part solved, because as just noted, the changing nature of trade-offs with relative satisfaction is incorporated. There need, however, to be additional procedures for adapting norms (changing the curves) as environmental constraints on goal attainment are reached or overcome.

Some other issues remain to be resolved before the approach can be used. For instance, there are really two criteria for policy selection. One is maximum movement up the curves of the graphs toward greater satisfaction of all values involved. The second is the achievement of as nearly optimal a balance among

FIGURE 4.3: EXAMPLES OF TRADE-OFF CURVES AMONG OBJECTIVE INDICATORS



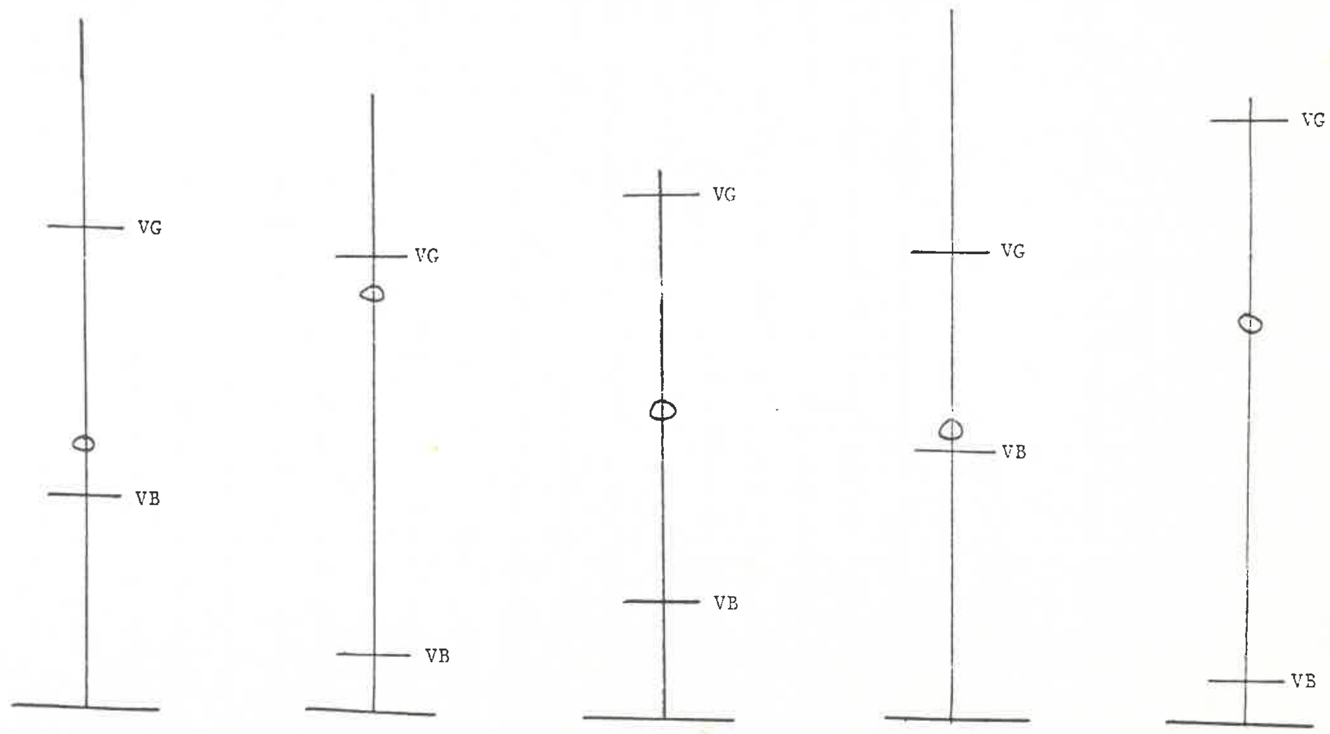
the operational indicators as possible--that is, the final state of the system would ideally lie on the curves. This is too great a constraint, however, and only relative balance can be obtained. The basic issue lies in the fact that movement up the curves and balance (trying to be near them) will very frequently be mutually contradictory efforts. Thus another "trade-off" between balance and value maximization, would need be specified. This is a problem, however, common to all approaches, so should not act to prevent adoption of this one.

Another minor problem in the approach is the need for comparisons of every objective scale with every other--thus the number of comparisons grows very rapidly as the complexity of the system directed and the number of indicators grows. An alternative approach, with many of the advantages of the trade-off method, but which avoids the large nunber of comparisons uses "satisfaction scales." Figure 4.4 shows how these could be used to associate an operational norm with different objective scales. A Likert-type scale[39] could identify for each value those states which would constitute very good and very bad (or very satisfactory and very unsatisfactory) conditions, as well as those conditions perceived as good, bad, and neither good nor bad.

This approach has most of the advantages of the pair-comparison method. A weighting system is implicit in the satisfaction scales as it was in the trade-off curves--at any particular time, those things are most important to the decision-maker which are least satisfactory. Interactive use with this approach would be even easier than with the trade-off curves, since fewer subjective judgments and comparisons must be made.

The cost of avoiding pair comparisons is paid by the satisfaction approach in the lesser information about relative value importance with different levels on the objective scales. Whereas the smooth curves of the trade-off graphs tell us this with considerable precision, the information from the satisfaction scales,

FIGURE 4.4: SATISFACTION SCALES



0 = Present Value

VG = Very Good

VB = Very Bad

with probably only 5 points, is much less detailed. It might, however, fairly safely be argued that trade-off curves would really be simply a smooth connection of the few points we could actually can identify. Moreover, the points of the Likert-type scale could be connected to form a continuous function. As we shall see later, this need not be and may seldom be linear against the objective indicator.

C. Overview of the Difficulties

Up to this point we have touched upon most of the major problems in representing norms for the control of decision processes. These include the establishment of a value set, the establishment of objective indicators related to those values, the representation on the objective indicators of operational norms (a function not just of the values, but of objective condition), and the description of norms change mechanisms. Because policy-making will require comparison of operational norms or values and require decisions about priorities, some kind of weighting system is necessary. The comparison across indicators and the weighting make the orthogonality question highly relevant. If the weighting is by indicator, then the indicators must be orthogonal; if it is by value, then the values must be orthogonal. Otherwise, of course, double weighting is introduced. On first reaction, the orthogonality problem might be very easily solved by a cluster analysis or factor analysis technique--quantitatively seeking non-related factors. But this ignores the fact that the indicators and value sets analysed may not produce orthogonal factors empirically, and if such are derived anyway they will be more abstract than we want.

Another difficulty, and one which has heretofore not been discussed, might be called the probability of outcome problem. In making decisions, value judgments must also be made about outcomes which are not certain. For instance, importing some energy is less expensive for most Western nations than producing all needed energy themselves. The value on this savings must be balanced against the value of a probabilistic outcome--the sudden cut-off of energy imports.

The following chapter presents an approach to the norms stratum which largely resolves these difficulties. It is based on a partly deductive but largely inductive approach and uses the satisfaction scale representation of operational norms. The approach would not be dramatically changed by the substitution of the trade-off curve approach.

5. An Approach to Value and Operational Norm Representation

A. General Outline of the Approach

This approach uses the conceptualization of values, operational norms and their interrelationship which was presented in Chapter 3. Thus values are basic dimensions, not directly related to objective scales--the indicators associated with operational norms serve as measures of value attainment. Exactly how this can be done will be discussed shortly. Operational norms are represented by a Likert-like scale associated with or superimposed on an objective scale, as discussed in the last chapter. The levels on that five point scale will be very good, good, neither good nor bad, bad, and very bad (VG, G, NN, B, VB)

Because values are fairly general, there may be several indicators which more or less well tap any value. Some indicators may also relate to more than one value. Figure 5.1 suggests the overall picture, with dotted lines representing weaker relationships. We can conceptualize the relationship in a factor analysis analogy. General values are factors, preferably orthogonal ones. They are thus not objective scales themselves, but an abstraction from the relationship among many. The various indicators are more or less related to the factors--that is, their loadings are higher or lower. Some variables or indicators load on more than one factor.

It is possible in factor analysis to create a measure of the abstract factor itself from the multi-indicators that load on it. The variables loading on the factor contribute to the combination measure depending on their loading on the factor and upon the independence of the variables (if a variable can be expressed entirely in terms of other variables, it makes no independent contribution). Again the factor analysis analogy is appropriate, because a measure of satisfaction on a value can be created from the operational norm measures of satisfaction associated with indicators of each value.

One approach to quantifying the loading of indicators on value factors was outlined earlier in the discussion of the Rand project. They asked respondents to judge the contribution of an indicator to a value on a four point scale:

3 Contributes strongly (or is pretty much the same)

2 Contributes moderately

1 Contributes slightly

0 Irrelevant

If SI_{ij} is the satisfaction level (on the Likert-like scale) of the system on indicator i of value j, and L_{ij} is the loading as determined by the above scale, then the overall satisfaction of value j (SV_j) is

$$SV_j = \frac{\sum_i SI_{ij} L_{ij}}{\sum_j L_{ij}}$$

The control by the sum of the loadings is necessary to remove the influence of this variable.

The above formula does not, however, control for the interrelationship of indicators. If some are measuring more or less the same thing, they are not making independent contributions to the variable and we would be weighting them too heavily by including them in the equation. The Rand corporation study also suggests a procedure for looking at the interrelationship of indicators (they used it in their cluster analysis). This requires a pair-wise comparison of all indicators on the following five point scale (I have reversed the numbers for reasons which can be seen below):

0 Practically the same

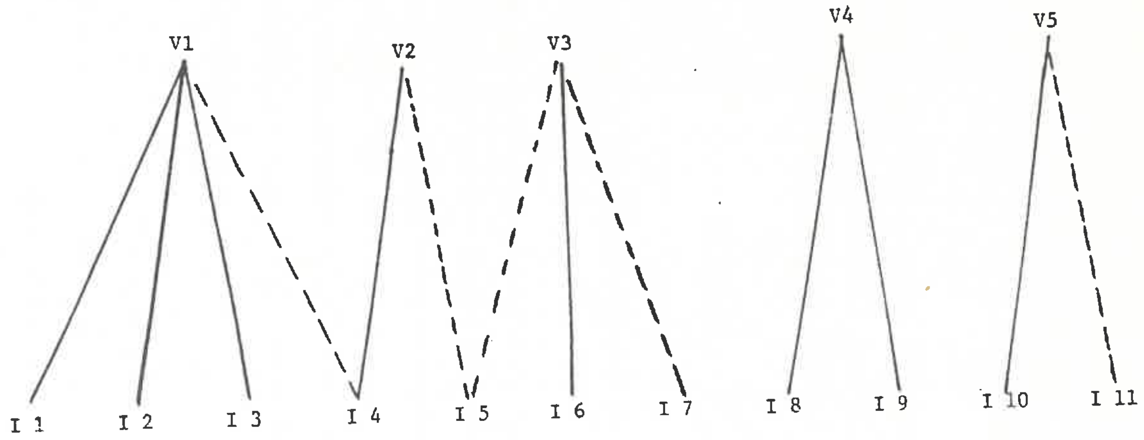
1 Closely related

2 Moderately related

3 Slightly related

4 Unrelated

FIGURE 5.1: INDICATOR-VALUE RELATIONSHIP



From such an analysis we could build a matrix like the following:

	I1	I2	I3	I4	I5
I1	0				
I2	3	0			
I3	2	1	0		
I4	3	4	1	0	
I5	1	0	2	2	0

The sum of the entries for each indicator then constitutes a measure of independence for it:

Indicator	Independence
I1	9
I2	8
I3	6
I4	10
I5	5

The sum of all contributions (SC_j) is 38. Thus each indicator's independent contribution to the value factor in this hypothetical example is $C_{ij}=Ind_i/SC_j$. The corrected version of the earlier equation is

$$SV = \frac{\sum_i SI_{ij}L_{ij}C_{ij}}{\sum_i L_{ij}C_{ij}}$$

The step to the computation of overall system satisfaction across all values is obvious:

$$ST = \sum_j SV_j$$

If the values are not orthogonal, they too can be adjusted for their independence.

Although the level of satisfaction on the indicators (SI_{ij}) clearly comes from the satisfaction scale discussed earlier, it must be remembered that the decision-maker acts not simply to maximize average indicator satisfaction, if doing so means great dissatisfaction on some items. Extreme levels on the bottom end of the satisfaction scale will be especially salient and their avoidance will be more important that the provision of extreme satisfaction.

Thus in essence overall satisfaction with indicators of any value will be a reflection of both the average level of satisfaction attained <u>and</u> the degree of balance among indicators. Again, extreme levels of dissatisfaction will be especially salient, and high levels of satisfaction on other indicators will offer little compensation. With these principles in mind, the following computation of SI_{ij} is offered as an attractive, but by no means the only procedure. The verbal points on the Likert-like scale can be connected to numerical satisfaction levels like this:

VG	5
G	4
NN	3
B	2
VB	1

The objective indicator level (OL_{ij}) can be represented on that scale. Satisfaction on any particular indicator can then be calculated as

$$SI_{ij} = 4 - (5 - OL_{ij})^2$$

This calculation leads to the following satisfactions associated with objective indicator levels corresponding to the five points of the Likert-like scale.

VG	4
G	3
NN	0
B	-5
VB	10

Clearly, this result has the generally desired characteristics. The contributions to satisfaction are positive and increasing above the neither good nor bad category and negative and decreasing below it. The higher levels of the Likert-like scale contribute decreasingly to indicator and overall value satisfaction and the lowest levels detract increasingly from it.

The last factor which needs to be discussed in connection with the measure of satisfaction is the treatment of future projections. Satisfaction with the current situation can be tapped with the equations outlined. For policy making purposes, decision-makers must evaluate the state of a projected environment. Future years will generally have decreasingly little weight in the overall picture. The degree to which the future is considered a valid criterion for policy direction will depend largely on two factors. First, societies which are currently doing well and are satisfied have the incentive to and the luxury of being able to plan ahead. Second, regimes which have an especially strong power base (entrenched authoritarian ones even more than popular democratic ones) will be able to accept the delayed gratification of desires which future emphasis implies. With future weighting factors, the final form of the satisfaction equation becomes

$$ST = \frac{\sum_t \sum_j w_t \left(4 - (5 - SVj)^2\right)}{\sum_t w_t}$$

where

$$SV_j = \frac{\sum_i \left(4 - (5 - OL)^2\right) L_{ij} C_{ij}}{\sum_i L_{ij} C_{ij}}$$

The establishment of an overall satisfaction indicator creates an essentially three tier approach, with total satisfaction (ST) at the top, value satisfaction (SV_j) in the middle, and the objective scales and operational norms at the bottom. This can be given a semi-institutional interpretation. At the total satisfaction level are the most important final balancers of decision-making: the chief executives and their watchdog agencies like the U.S. Office of Management and the Budget. In the middle are the major societal concern breakdowns, corresponding to cabinet officers or ministers and their departments. Interestingly, governments seem to have the same orthogonality problem here that we do--jurisdictional problems arise constantly. At the bottom level are the indicators which represent the kinds of things watched up at minister level. This semi-institutional interpretation could lead to a semi-institutional heuristic procedure for translation of the satisfaction measures to policy. This issue will be picked up again in Chapter 7.

Although many details remain to be specified, this approach to satisfaction analysis can direct a policy simulation. Before we turn to those details, the satisfaction formulation should be explored in more depth.

B. Weighting

An issue has been made of the need to avoid double weighting and therefore of the need to add a "contribution" factor to the value satisfaction measure. Although it is probably quite clear, we have not directly broached and answered the question of how weighting of priorities _does_ enter. Obviously, for instance, when a society has insufficient food supplies, food provision will take priority over other desires (although as India shows, this must be qualified).

The satisfaction scales are self-weighting. They weight the importance of the indicators associated with them in two ways. The first is most obvious--the location of the scale _vis-a-vis_ the actual level of the system on that scale tells the system whether attention must be given to the item. In the food example, if the food supply were inadequate, the very bad level of the satisfaction scale would lie in the neighborhood of the current level of food supply, and because of the large negative contribution of a very bad indicator level to the value satisfaction measure (a -10, see above), the food issue would be highly salient, and steps would be taken to correct it. In fact, the system would improve its overall satisfaction if it had to bring two other indicators down from very good to the NN level (a total loss of 8 on the satisfaction measure) in order to bring the food indicator up to NN (a total gain of 10).

Actually, the provision of food and other bare survival needs may be so important to the system that even the weight discussed here is too little. The next chapter, on norm change will present the notion of a "survival minimum" on the operational norm scale, leading to even greater efforts to improve the situation. That chapter will also discuss how the norms can be set and changed.

The second type of "weighting" done by the satisfaction scale might better be called intra-indicator weighting to distinguish it from the inter-indicator weighting discussed above. Essentially, the satisfaction scale can be used to give some information about the marginal utilities of changes at different levels on the objective scale. Figure 5.2 shows a variety of satisfaction scales, each suggesting something lightly different about the affect associated with the related objective scale.

Scale 1 is a basic symmetrical pattern, and will serve as reference point for the discussion. Scale 2 illustrates how the scale can indicate variable marginal utility. That scale implies that it is very important to the system to maintain a certain level (around NN) of the item indicated by the objective scale. If the system drops below that level, dissatisfaction increases quite dramatically. On the other hand, once a basic level on the indicator is reached (that is, NN) additional increments have considerably decreased marginal utility. This could be a fairly common pattern of operational norms, especially for items necessary for survival like food. Scale 3 is a reversal of number two. Here, the increments above NN have greater marginal utility (or weight) than those below. This pattern, although theoretically possible, should occur infrequently. It suggests a kind of threshold or critical mass phenomenon. Up to a point, increments mean little; then they become important (as in a nuclear reaction). Scales 4 and 5 are shrunk or stretched versions of number one. These indicate either different objective scales than Scale 1, or different weights of the value involved on a similar objective scale. Clearly Scale 4 suggests greater weighting than Scale 5. Scale 6 again indicates either a different objective scale than that associated with satisfaction Scale 1. or higher "goals" and heavier weight.

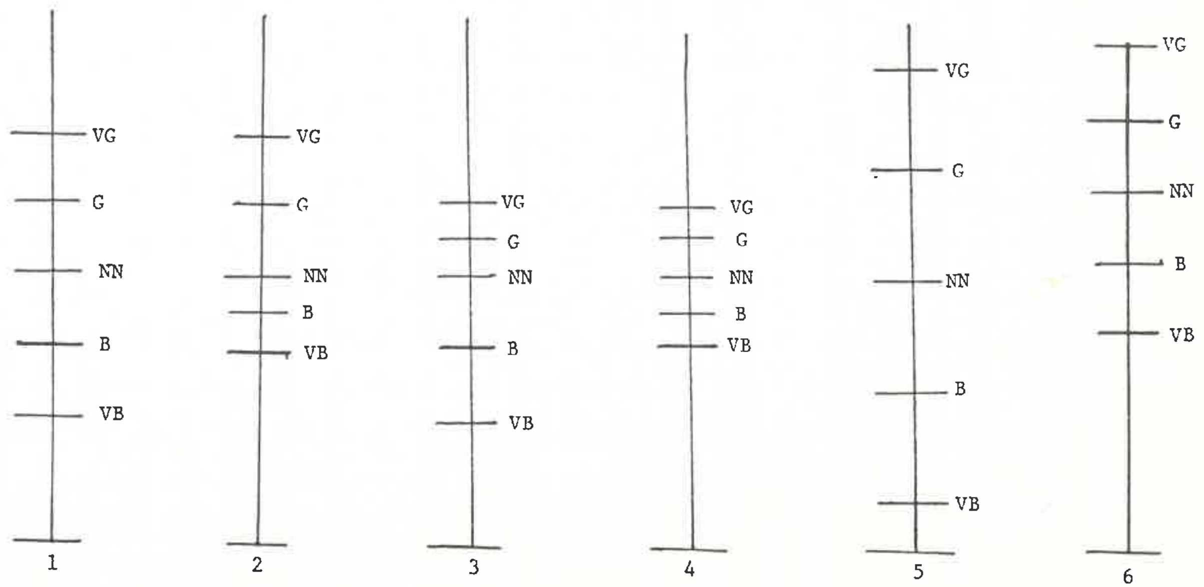
The nearly infinite variety of satisfaction scale patterns possible suggests the complexity of inter- and intra-scale weighting potential.

C. Probability of Outcome

There are a number of value judgments made in the policy selection process concerning policy outcomes which are highly uncertain. Actually, of course, few if any policy outcomes can be said to be certain--they are all probabilistic. Many however, are high probability outcomes. Two examples should clarify this. Nuclear plant explosion is a low probability outcome of policies building any one nuclear plant. Because of the highly negative value placed on such an outcome, it becomes part of the decision calculus (a low probability outcome with neither high positive or negative valence would not be important in the calculus). Similarly, dramatic energy shortage and economic catastrophe is a low probability outcome (although now perceived to be higher than we realized a year ago) of energy policies causing reliance on imports.

The satisfaction scale based evaluation procedure assumes that we can project the outcomes of policies, look at them in terms of the satisfaction measure, and thus evaluate both outcomes and policies. For high probability outcomes (very near 1) we can probably safely ignore the probability question altogether. Actually the incremental policy approach to be discussed in Chapter 7 also grows from the probability issue--as your policies diverge more and more from the tried and tested ones you used before, the uncertainty of outcomes increases, and it is

FIGURE 5.2: PATTERNS OF SATISFACTION SCALES



in good part the negative reaction to that uncertainty itself (and not the anticipated outcomes) which weighs against major policy shifts.

Thus we want to address the question of low probability outcomes, with high value content, associated with policies in the neighborhood of those applied at any given time. The two diagrams in Figure 5.3 represent the issues involved. The factors that are important for the judgment of policies are the consequences of the probabilistic outcome (the difference between the situation with and withou the event) and the probability of the outcome. Actually we can perhaps combine them and speak of the probabilistic outcome. For instance, in the nuclear plant example we might use:

$$\text{Probabilistic Annual Deaths by Nuclear Accident} = \text{Annual Probability of Accident} \times \text{Deaths/Accide}$$

This sort of "objective scale" could thus be introduced into the indicator set loading on an environmental quality value, and a satisfaction scale could be associated with it. Because of the introduction of deaths into the indicator, most interactors whoset satisfaction levels might be biased. To reduce such bias, the indicator might need be translated into something like comparable CO_2 levels (comparable say in terms of reduction in years of life).

Clearly this is not a simple sollution to the probability problem. It becomes even less simple when you realize two things. First, the nuclear accident situati is much more complicate than plant blow-up probabilities--theft of material and nuclear waste accidents are two of the additional issues involved. Second, the important probability is perceived probability, not empirical probability. (if such is even computable) Yet this solution seems a quite reasonable approach to an extraordinarily difficult issue.

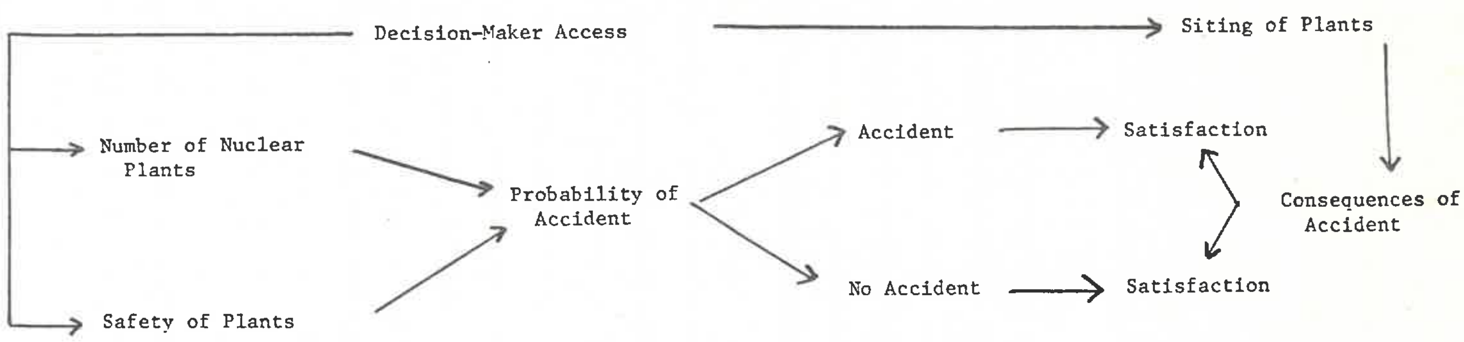
In the energy case, an objective scale could be:

$$\text{Probabilistic Annual Dollar Cost of Energy Imports} = \text{Annual Probability of Cut-off} \times \text{Dollar Cost of Cut-off}$$

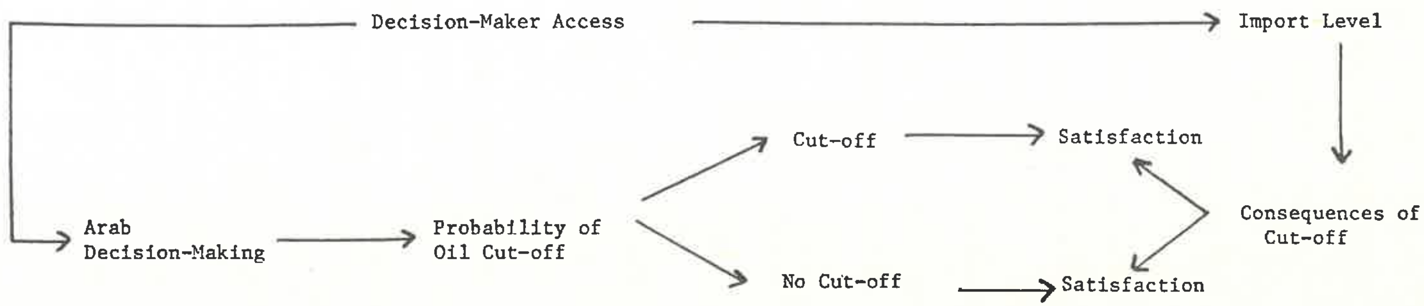
Here the probability is even more subjective. Any fully simulated model using

FIGURE 5.3: PROBABILISTIC DECISION SITUATIONS

1. Nuclear



2. Energy Imports



this approach would need a routine to calculate perceived probabilities (for interactive use, the model user could be asked). A major factor in perceived probabilities would be past occurrences--a memory concept could be used, with perceived probabilities decreasing as time since the last occurrence of an event increases. Again also, the probabilistic function above is oversimplified. Ideally we need an integration function over various levels of cut-off, their economic consequences and their probabilities.

If such a function could be derived and used as an indicator, it would allow easy comparison with the dollar benefits of importing cheaper energy. This does not mean that a balance would be struck--conservatism and fear of the uncertain would probably lead to an uneconomically low level of imports (as it probably has historically in the U.S.). This is an example of a case where largely identical objective scales (dollar costs) could have different satisfaction scales associated with them and thus different "weights."

There is a second possible approach to the probability question. In some cases it would not be at all unreasonable to use the policy itself as an objective scale indicator, and to have a satisfaction scale associated with it. Consider, for instance, the amount of money spent on national defense. This is clearly a policy, and the desired and probabilistic outcomes are avoidance of war and successful conclusion of wars when they occur (i.e. the value involved is "national security"). But the probability distributions associated with various levels of defense spending are so complex and uncertain that there can hardly be even said to be a societal or decision-maker perception of the distribution. In this case, the defense budget size itself has become the determinant of satisfaction.

Looking back at Figure 5.3, the same could basically be said about the energy situation. Import levels, basically a policy, have become the real focus of attention and satisfaction or dissatisfaction--the <u>actual impact</u> of cut-offs or embargoes has until recently hardly been discussed. This contrasts, however, with the nuclear situation. There the probability of nuclear accidents and their consequences has always been at the center of attention. The reason, presumably, is the better data available. Perhaps then the issue is really the shape of the perceived probability distribution. If it is relatively well-known and peaked, as it is for nuclear accidents, something like the above suggested measure of probabilistic nuclear death rate should be in the indicator set. When the probability distribution is especially unclear or flat, the relevant policies themselves can be used as objective scale indicators.

D. Example Value and Indicator Sets

Table 5.1 presents one possible set of values and indicators for use across a wide variety of simulated environments. The values suggested are those developed in Chapter 3. These touch on biological, social, and ego systems. If the UTOPIA approach is applied to decision-making for a less comprehensive environment, the value set can be reduced accordingly. That means, naturally, some error, but model builders and simulators purposely accept some error as the cost of simplification. The orthogonality of the values must be a concern for us in looking at overall system satisfaction, just as it was among indicators of a given value. The values in the set were developed to be as distinct as possible. If interrelationships are felt to exist, the same sort of contribution or independence approach can be used for the overall measure as for the individual value measures.

The indicators listed are meant to be illustrative only, and not to be adequate in themselves. One of the tasks of the project has to be to develop a good set of indicators. The many social indicator studies should be of help--so should the somewhat deductive structure of value categories. That structure clearly does show the bias of the social indicator movement towards higher level values.

TABLE 5.1: EXAMPLE VALUES AND INDICATORS

VALUES	INDICATORS
Food	Calories/capita Protein/capita Animal Fats/capita Distribution of calories Distribution of protein Distribution of animal fats
Shelter	Meters^2/capita of housing Rooms/capita Bathrooms/capita Heated meters^2/capita of housing
Medical Care	Doctors/1000 Hospital Beds/1000 Distribution of doctors
Environmental Quality	Ppm CO_x Ppm NO_x Ppm Dust Park area/capita Water Quality Exposure to noise Radioactivity above background Probabilistic safety hazard of nuclear plants Thermal pollution
Material Well-being	Income/capita above food, shelter expenses
Physical Security	Percentage of GRP on defense Crimes/1000 Policemen/1000
Family	Abandoned children/1000 Child abuse incidence/1000 Hours of family member contact/week Subjective question (?)
Non-family Social	Average group memberships/capita Distribution of group memberships Hours/month of non-job social contact

TABLE 5.1: EXAMPLE VALUES AND INDICATORS (CONTINUED)

VALUES	INDICATORS
Formal Education	Average years of schooling Distribution of formal education
Self-improvement Opportunity	Annual travel days/capita Library volumes/capita Leisure hours weekly

When used in place of material well-being, shelter, and medical care:

Economy	GRP/capita Distribution of GRP Probabilistic GRP cost of energy imports

One of the critical issues concerning indicators will be to develop an adequately broad set to tap all aspects of a value. For instance in the case of food, both average availability and distribution are important. These are two aspects of the food situation which are almost independent of each other; just as park land/capita and radioactivity level have no relationship, but both are measures of environmental quality.

It might again be argued that unwanted weighting will be brought into the procedure through this mix of indicators. In the case of food, does it matter if we have three average food indicators and three distribution as opposed to three average and one distribution? The answer is no! Because the independence of the contribution of each distribution indicator is markedly lower with three than with one, the total weight in the value measure will be very much the same. In fact, if the members of the set of all distribution indicators are judged to be "practically the same" as are members of the set of all total food indicators, and the two sets are judged to be "unrelated," then the total value satisfaction indicator will be identical no matter what number of each set is included.

Someone might still argue that keeping the two quite distinct dimensions as essentially equal components of the food value, and having the system maintain balanced satisfaction on the two is weighting the two incorrectly, since societies pay less attention to distribution than to averages. To begin with, they need not be treated as equal components. If it is felt that total food contributes more to the value placed on food than food distribution, this will show up in the relative loadings. Even if the loadings were identical or equal, however, "weight" would not be. This is where the self-weighting character of the satisfaction scales come in. If societies pay less attention to distribution, that is equivalent to saying that they are more easily satisfied and that their satisfaction scale is lower on the objective scale of distribution than on that of average food.

The discussion of the average food and distribution of food indicator mix raises another interesting issue. In the next chapter we will suggest that operational norm scales increase slightly from year to year (especially in regions used to "progress"), in a kind of reality testing process. This would suggest that over time, distribution issues, not just in food but in economic welfare and other value areas, should have caused some dissatisfaction in the Western developed countries, because distribution patterns of wealth and other resources have not changed a great deal. Would this norms stratum approach thus misrepresent the historic pattern? No, because absolute (and average) levels have gone up quite regularly and significantly. The satisfaction contributed by these indicators would have in part off-set distribution dissatisfaction. If total food is loaded on the food value more heavily than food distribution, as it probably is, the entire dissatisfaction component of the latter could well be offset. But the model approach would suggest that a considerable latent dissatisfaction exists and that if the high satisfaction contribution of absolute levels were to cease, for instance because of failure to continually increase those levels, distribution issues would come to the fore. We can already see this in developed society food policy; the total consumption is peaking, and emphasis is switching to distribution. In the economic well-being issue are it can be assumed that the same would happen.

This discussion of indicator weighting and balance can be continued in the context of the environmental quality value. Someone with a major concern at the moment with the hazards of nuclear plants might well ask if these concerns would not be "drowned out" by the presence of so many other indicators of other types of environmental quality. The answer to this must be largely affirmative. In fact that may well be part of the reason for the current momentum towards nuclear power in spite of such critics. Moreover, nuclear plant replacement of fossil fuels actually decreases some other types of pollution, offsetting to a large degree the dissatisfaction with those plants.

If the projected (and perceived) hazards of nuclear power become increasingly unsatisfactory, however, the high weighting given in the approach to unsatisfactory indicators will eventually force attention to the issue. A key factor here is perception. In the probabilitic consequences formula, it is perceived probabilities which enter. One major nuclear accident could dramatically change the situation. Another key issue is the time horizon of decision-makers. The rapid growth of the nuclear energy component means that a time horizon extending only 5 or 10 years contrasts markedly with one of 25 years.

The indicators suggested for physical security raise another point. There is a rather clear pair of subdimensions--external and internal security. It could be that these should constitute two distinct values. Whether they constitute one value together or two separately can, unfortunately, affect the total system satisfaction. Together in one value they each will contribute, as quite unrelated subdimensions, approximately one-half to the total value satisfaction, rather than the full amount of independent values. The impact of value combination or separation will depend on the degree to which the system is able to maintain a balanced satisfaction level across and within values. If the system maintained a perfect balance, combination or separation would have identical results. When two value elements, like internal and external physical security appear "independent", they should be affected by relatively different policies. In that case, trade-offs should be possible to achieve relative balance, and the decision system Chapter 7 describes will act to obtain it.

To understand this situation better, contrast it with an opposite one. Suppose both doctors per 1000 and nurses per 1000 were elements of the medical car value. Suppose further than the level of satisfaction on the number of docters per 1000 was "bad" and that on nurses was "good". Building medical schools would increase the satisfaction on doctors per 1000, but also on nurses per 1000, since the two are quite efficiently and frequently trained together. Thus it becomes difficult to obtain a balanced satisfaction level across the two indicators. The procedures outlined in this chapter work to properly compute a medical care satisfaction score by loading the two related indicators and controlling for the independence of their contributions. In the case of internal versus external security, if internal security is evaluated as bad and external as good, the resources can be shifted between them to balance the two because in fact they are independent. We may be seeing this in the United States, where the percentage of the GRP spent on external defense is decreasing and the percentage spent internally is increasing; eventually a balance of satisfactions should be reached.

There probably exists no neat solution to the problem. That outlined in this chapter is reasonable, but it requires one additional element which Chapter 7 will add. In order to avoid too little emphasis on any indicator of a value, because for instance, of combination with and dilution by others, the decision procedure will single out those on which dissatisfaction is lowest for special attention, regardless of the overall satisfaction with the value. In the case of nuclear hazards raised earlier, this will mean that efforts to prevent hazards will not be de-emphasized because the environmental problem is not seen, but if in fact they are de-emphasized, because of too great a cost to other indicators and values.

6. The Mechanisms of Operational Norm Change

Values were earlier defined as unchanging dimensions. Thus they do not come and go in the decision process, but are instead relatively emphasized and de-emphasized. The mechanisms for this are two. First, the state of the environment can change, causing dissatisfaction (value emphasis) where there was none before, or satisfaction (value de-emphasis). Second, the operational norms themselves can change. That is the subject of this chapter.

A. The Original Establishment of Operational Norms

Ideally, two procedures should exist for operational norm setting. The first is the interactive establishment by a model user. It has already been noted that one of the advantages of the satisfaction scale approach lies in the relative ease of interactive creation. Ergonomics could develop efficient procedures, quite possibly with cathode ray tube displays and light pens.

When we wish to explore the impact of actual system values, we will need considerable research to extract appropriate satisfaction scales (or other operational norms) from sources like the Human Relations Area Files. Either supplementing or substituting for such research could be "expert judgment by individuals or panels. Supplementary use of that technique makes more sense.

Some general principles of operating norms can be listed. First, such norms will weight values by the general level in human need inventories--biological needs first, especially food; then social and individual needs. This means that in less economically developed societies, satisfaction (insofar as governmental priorities are concerned) with the indicators of higher level values will be good, or at least not bad, and it will be the lower value indicators on which relative dissatisfaction shows. For more economically developed societies, satisfaction with indicators of biological need related values will be high and relative dissatisfaction will begin to appear on higher order values.

There may exist some cultural differences. If the distinction between sensate and ideational cultures is valid, and not merely a reflection of resource differences, more ideational cultures would be satisfied on biological level values at lower resource levels than ideational cultures.

In general, satisfaction scales will contain and be nearly centered on present values of indicators. The studies of Cantril show that in nearly every nation, individuals perceive the present state of affairs for both the individual and the nation as near the middle of a 10 point self-anchoring scale analogous to the proposed 5 point Liker-like scale. The exception to this principle should be situations which are so appallingly bad as to clearly be near a "survival minimum." The very bad end of the scale should never fall below such a minimum, and thus the individual would perceive such a situation as bad. Even the average Indian, surprisingly, did not perceive his present situation at the bottom of the scale (value 1), but at 3.7. When Indians were asked to evaluate the situation of the entire country, their national ratings averaged 4.9. Of the nations sampled by Cantril, people in the Dominican Republic perceived themselves as in the worst shape--average personal rankings of 1.6 and average national ratings of 2.7.

The differences between the citizens of India and the Dominican Republic cannot be explained by the difference in actual conditions: the GNP/capita in the Domican Republic stands at more than double that of India. Instead, another principle makes sense: operational norms are strongly affected by what is perceived as and/or found to be possible. Perceptions of the potential movement on objective scales come from domestic referents, external referents, and personally based knowledge of feasibility. In both India and the Dominican Republic some segments of the population live <u>much</u> better than others. In India, however, the rigidity of the social structure may have retarded aspirations of the less fortunate; in the Dominican Republic there has been relative (if little) mobility.

Citizens of the Dominican Republic also have the example of fairly significant movements towards prosperity by other Carribean nations and that of the Colossus to the North. Finally, both nations have experienced some limited growth and progress in living conditions. But the experience in the Dominican Republic came before W.W. II, and that of India largely after the war. In the 1950-65 period, Indian GRP per capita grew at 1.7% annually compared to .9% in the Dominican Republic (and a negative rate in the early 1960s). Students of revolution have argued that one of the causes of greatest popular discontent lies in a change from progress to stagnation. Progress causes aspirations and expectations for continued progress, and its cessation can cause a "revolutionary gap" between the operational norm and the objective conditions. From the viewpoint of domestic stability, no progress is better than intermittent progress. The Dominican Republic regime survived this situation only by the use of government force, and with the assistance of U.S. troops. If Indian growth now slows down, a revolutionary gap will inevitably develop.

These general principles and some research can produce the necessary initial levels of operational norms. They can also direct us toward some rules for norm change, as discussed in the next section. Cantril's studies of populations have been cited here as examples, but a caveat is in order. Decisions reflect the norms not of the entire population, but a combination of decision-maker norms and norms recognized by decision-makers as those of society (and which probably are those of the middle and upper classes dominantly). We can never hope to represent all of the complexity of norms representation and perception. Two potential surrogates exist. One is the norms of the decision-makers themselves, insofar as we can define them. If we could tap these norms directly through decision-maker interactive participation or through questionnaires it would be useful. The second surrogate lies in those with the same general demographic characteristics as decision-makers

For instance, in the U.S. upper and middle class male WASPs hold attitudes close to those of the decision-makers who come from that group. Cantril's data, available from the Inter-University Consortium for Political Research in Ann Arbor, could provide the norms of "establishment" groups in the countries he examined.

B. Operational Norm Change

In the change of norms as in the original establishment, the interaction between objective scale levels, perception of objective scale potential, and the operational norm is basic. The psychological principle that humans act to reduce cognitive dissonance among these elements underlies many of the following ideas:

1. Operational norms will move up an objective scale as the situation improves.

2. Operational norms will move down an objective scale as the situation deteriorates.

3. Operational norms will move up an objective scale towards the situation of a referent.

4. Operational norms will move up an objective scale with an increased opportunity for situation movement such as a technology change.

5. Situation movement upward on an objective scale will generate a momentum of operational norm upward movement.

6. Operational norms will move towards an "action-sanctioned" situation level.

7. Both upward and downward resistance levels of operational norm change exist on many objective scales.

Before moving to a discussion of the individual operation of these rules, some justification of what may at first glance seem an obvious formulation should be given. To the best of my knowledge, there is no similar discussion of formulation of the ways in which the goals and expressions of societal satisfaction change.

The utility of these notions can perhaps best be illustrated by examination of a paragraph from Rescher's study of value change, the only other general discussion of value change I have seen:[40]

> '<u>Cleanliness</u>' comes cheaper in modern cities than in medieval ones, and the achievement of '<u>privacy</u>' costs more in urban environments than in rural ones. The maintenance of a value will obviously be influenced by its cost. When this becomes <u>very</u> low, we may tend to depreciate the value as such. When it becomes very high, we may either depreciate the value in question as such (the 'Fox and the Grapes' reaction)--or rather more commonly--simply settle for lower standards for its attainment.

To begin with, there seems a logical inconsistency here--values can be depreciated when costs become higher or lower. This problem aside, the processes seem clearer when translated into the conceptualization of values and the norm change rules of this paper.

Cleanliness and privacy are general values in Rescher's discussion. Values are scale-less dimensions. A number of objective scale indicators can be associated with each, and operational norms established on the indicators. In the case of cleanliness, the objective situation has improved since the middle ages, because of the pull of operational norms and the reduction of barriers (e.g. costs). The operational norm level has moved up the scale of the cleanliness indicator with the objective situation. This does not imply a depreciation of the value--in fact it suggests the opposite. If people were transported back to the middle ages with today's operational norms, they would be appalled by the standards of cleanliness. It does not even imply a relative decrease in emphasis on the policy. People in both time periods may well characterize the actual situation as neither good nor bad. If medieval populations characterized food and shelter conditions as bad and contemporary Western populations characterized theirs as good, the importance in terms of societal and individual decision-making of the cleanliness, value (i.e. its <u>relative</u> importance) could be higher today than at that time. The environmental movement can be explained in such terms.

More likely, of course, some sort of balance of values is maintained in all periods, and the relative satisfaction with cleanliness levels remains largely unchanged.

In the case of privacy, we will for discussion's sake accept Rescher's hypothesis that the situation on an objective scale may have deteriorated for those people who moved from rural to urban environments. That would cause an increase in dissatisfaction as measured by the associated operational norms. In the short run, the value would receive additional weight relative to other values contributing to individual overall satisfaction. In the longer run the operational norm would adjust to the situation and in some sense, as Rescher says, the value would be depreciated. Both the discussions of privacy and cleanliness have ignored the possibility of upper or lower resistance areas to operational norm change. If the decrease in privacy were so great as to threaten physical or physiological health, the operational norm would never adjust completely, and a continued dissatisfaction with the situation and relative weight on the value would result.

C. More Details on Operational Norm Change

The upward or downward movement of the operational norm with the objective situation appears a logical consequence of cognitive dissonance reduction. As a situation becomes "very good," we see the potential for further improvement. With that potential there, we can hardly continue to conceptualize the situation as "very good," and it gradually approaches "neither good, nor bad." This reaction seems to have surprised some students of social indicators and policy:[41]

> In the past it may have been presumed that behavior could be predictable given sufficient knowledge of the objective situations which underlie it. Recent social history, however, has done little to reinforce this position. For example, while improvements over time can be shown in such objective measures as real income, housing quality and health, evidence bearing on the experiences of personal satisfaction with income, housing and health do not show corresponding improvement. Periodic Gallup surveys, for example, addressed to the subjective aspects of global 'happiness,' do not show a considerable increase since the end of World War II."

The authors draw the conclusion that both objective and subjective indicators are important, but do not go the extra step of focusing on the relationship between those two as the real basis for individual and social action.

We need information about the speed with which and the extent to which the norm will adapt to the situation. Some rules can be suggested. The upward movement or adaptation will occur more easily and more rapidly than the downward movement. We accept the good more readily than the bad. The rate of norm movement will depend upon the ease and speed at which the situation changes. If a technological change allows very great increases in satisfaction or a natural disaster leads to very great decreases, we will adapt our norms fairly rapidly (again more slowly with a disaster). A rule that the norm change is a fixed proportion annually of the gap between it and the situation does not seem unreasonable. Similarly, a reasonable rule would be that adaptation of operational norms to the situation of a referent should depend on and be roughly proportional to the gap between your situation and the referent's.

Some cultural and regional factors could be important. In particular, past experiences with change in the objective indicators would be critical. Regions used to "progress" would adapt readily. Similarly, there may be regions used to regression. General societal philosophies about change in the human state, for instance linear or cyclical theories of history, could provide data here. It may well be, for instance, that good harvests are seen as cyclical phenomena in India, but that increasing agricultural production has come to be a linear expectation in the U.S. This would imply a slower change of operational norms on food with its actual availability in India than in the U.S.

Upward and downward resistance levels have been mentioned, but not yet discussed. Physical survival level on any indicators poses the most important downward resistance levels. The "very bad" evaluation of the operational norm should never drop below a survival level, and there should be resistance while approaching it (hence the term "resistance level").

Upward resistance levels can be divided into two kinds--objective ones associated with the objective scale and value ones associated with the operational norm scale. It is important to maintain the distinction. Physical or objective resistance levels mean that there is a limit on performance by the indicator. For instance, zero environmental pollution would pose an absolute limit on pollution indicators. Other indicators of environmental quality than pollution levels may not have the same resistance level if the environmental quality can be improved beyond the elimination of pollution (e.g. elimination of nuisance insects). In addition to the absolute limits, some indicators may have temporary limits--the halting of increases in average longevity at birth in the 65-70 range may pose such a limit. There is little reason to assume a permanent barrier at that level. The physical or objective barriers come to be reflected in the operational norms. For instance, if people in their twenties were asked to attach a satisfaction scale to various lengths of their lives, the center of most scales would be around 65-70 or slightly higher. Naturally, of course, as those people turn 60, some upward shift will almost inevitably occur on the satisfaction scale.

Abraham Maslow's concept of "peak experience," that is the satisfaction of a need, suggests the possibility of a value-related rather than an objective upward resistance level at which the peak experience takes place. We can easily see such an upward resistance area on a value like food. The U.S. appears to have reached a point on fat consumption/capita and calories consumption/capita above which little value is placed on food. At this point the operational norm scale will cease its movement upward even though the objective indicator could increase further. Similarly, on the level of social needs, the notion of being "smothered in love" implies an upper resistance area there, too. The "peak experience" concept also suggests that there may be a downward resistance level at the same objective level. Presumably a "peak experience" is a kind of threshold phenomenon, with the marginal utility of objective unit increases at the peak greater than that of unit increases below the peak. Interestingly, this can be related back to the earlier discussion of satisfaction scale patterns and weighting--it would be possible to represent this downward resistance level by "scrunching up" the satisfaction scale as it reaches the upper resistance level, so as to provide those last units with the additional marginal utility. In reality, however, the existence of this downward resistance level at the peak experience is perhaps too uncertain for us to simulate it.

An alternative interpretation of upward resistance levels is the counteraction of different values on the same objective indicator scales. Thus additional units of food consumption/capita may be valued in the context of social or psychological needs, but become increasingly a threat to health. Similarly, additional social ties (love and belongingness) may increasingly serve social values at the expense of self-actualization. Thus the upper resistance levels could represent a normal "balance" point between the two sets of values. Although this interpretation may help us establish such levels, e.g. in the case of food, it is probably unnecessary to explicitly develop the complex linkages of value objects with different basic needs at different objective levels.

There is one more issue to be considered in norm change. Is there a "natural" or "desired" balance of progress across basic value objects? For instance, we might argue that when a temporary physical resistance level is reached by an objective indicator and maintained for some time, the removal of that barrier will release pent up desire for progress which will work to help the value catch-up to its rightful place in the value hierarchy. This may appear a natural implication of value hierarchies. Yet after considerable thought, I see no merit in the notion, with one exception. If the temporary barrier were to hold the indicator level very near the lower resistance (survival) level, e.g. as with food production in India, and that barrier were removed, a sudden surge of effort might be expected. This situation, however, is quite adequately handled in the present approach--since the very bad end of the satisfaction scale cannot fall below the resistance level, constant striving for considerable increase in the objective level would result. Removal of the barrier would simply facilitate this. Above the survival level, there may be no "natural" balance among value objects. We can all point to many seeming imbalances even within our own culture, from the perspective or our individual value preferences, e.g. the spending of more money on cosmetics, tobacco, and liquor than on medical care and research. Thus no procedure for any such balancing effort is recommended here for the descriptive simulation of society; users can provide their own balance through initial satisfaction scales for prescriptive analysis.

D. Rules for Satisfaction Scale Change

More than any other specification of procedure in this report, the specification of operational norm change rules needs more thought and research. Simply as an illustration of such rules this section offers a sample set. The rules have a priority order in which each rule has priority over all of those with higher numbers:

1. The satisfaction scale can never cross an upper resistance level with the very good and of the scale or a lower resistance level with the very bad end.

2. a. The very good end of the satisfaction scale can never move more than 10% of the distance to an upper resistance level, if there is one.

   b. The very bad end of the satisfaction scale can never move more than 10% of the distance to a lower resistance level, if there is one.

3. Upward and downward changes of the satisfaction scale are not the sums of the rules to follow, but the maximum of any one rule, within the constraints of rules 1 and 2.

4. a. The center of the scale will move upward 33% of the distance between it and a higher objective reality.

   b. The center of the scale will move upward whatever percentage of the total scale length the overall satisfaction indicator changes, but not less than 5%.

   c. The center of the scale will move upward 10% of the gap between the scale center and its reference region reality.

   d. The center of the scale moved downward 5% of any decrease in its reference region reality.

   e. The center of the scale moves downward 10% of the difference between it and a lower objective reality.

   f. After action is taken (a decision made), the middle of the scale is adjusted 20% of the gap between it and reality.

The reference region for all regions in the M-P model is North America. That region has no reference region for upward reference, and Western Europe can serve as a downward referent.

Note that these rules will prevent major dissonance between objective situations and operational norms. Regions making progress on indicators and with high objective levels relative to other regions will be generally slightly above NN in satisfaction. Regions not making progress and/or with lower objective levels than other regions will be generally slightly below NN in satisfaction. Regions with low objective levels and not making progress will generally be quite dissatisfied.

7. The Linkage to Decision-making

A. General Conceptualization of Affective-Cognitive-Behavioral Linkages

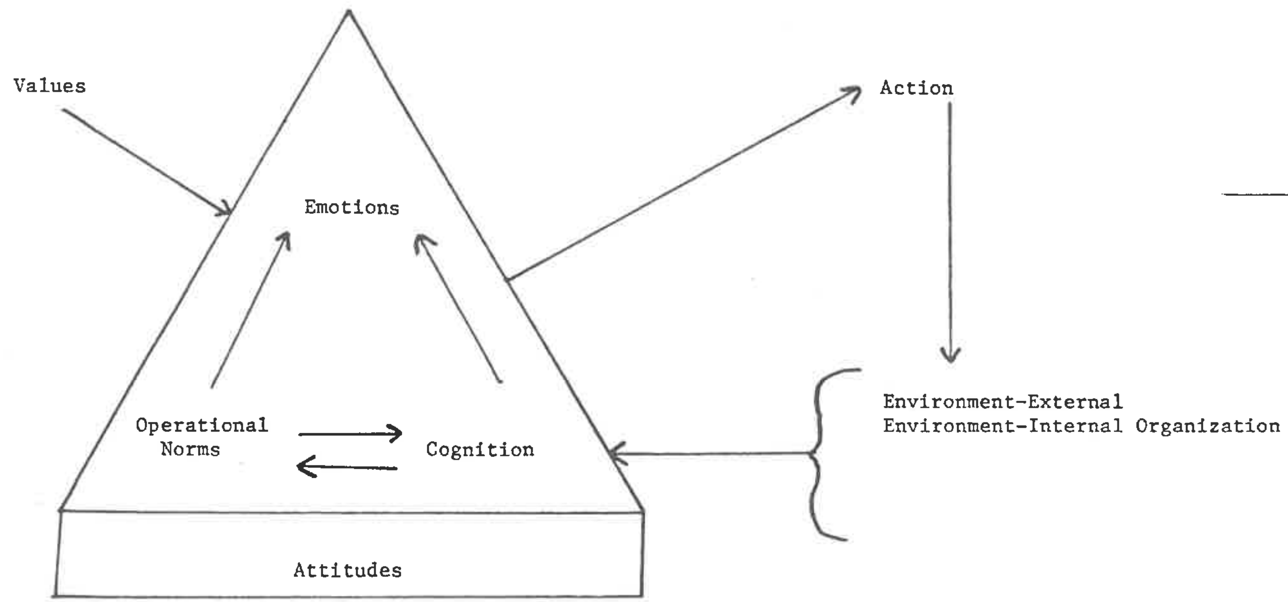
Earlier the psychological conceptualization of attitudes as consisting of affective, cognitive, and behavioral components was presented. To integrate the prior discussion with a policy-directing procedure, a related but slightly different conceptualization is needed. Figure 7.1 shows the major components and linkages of this study. The affective components of that diagram have received nearly all of our attention to this point. We have talked about values as dimensions free from an objective context and as invariant--no other factors affect them. Values and the perception of the objective state of the environment, one aspect of cognition, interact to shape operational norms. One component of the attitude triangle we have not talked about is emotion. Emotion arises with sudden and major dissonance between the cognitive and operational norms components, that is when large gaps between the objective scales and the satisfaction scales emerge. This usually will come about with a sudden change in the environment and our perception of it, e.g. a family death, a burglar, famine, or war. The satisfaction scale approach represents emotion as a major weight on the dissatisfaction end (and sometimes on the satisfaction end) of the scale.

It may appear rather unusual to introduce a concept like emotion into a societal policy making simulation approach. In fact, the approach will represent it only implicitly in the value satisfaction calculation, and not explicitly. The concept of emotion can, however, help explain the occurrence of sudden and difficult to predict governmental actions. In pre W.W. II Germany, the economic catastrophe of the Depression created emotions which supplemented those to which the settlement of W.W. I gave rise. The resultant desperate actions could hardly be predicted by any policy simulation we develop, but the potentiality of them could be. Similarly, we can suggest that the emotions caused in India by a massive famine could lead to desperate action, not excluding threats to use their new atomic "device."

The cognitive element of Figure 7.1 will receive much attention in this chapter. That element has three main components. First, the perception of the state of environmental affairs constitutes an important part of the cognition of both individuals and governments. We have talked about the objective scale associated with operational norms and the situational or real level on that scale. What we actually mean is the perception of reality. On some indicators misperception could be significant; we will continue to use the objective situation presented by the simulation as the best representation of that component of cognition. The second component of cognition is a "cognitive map" of the environment.[42] This environmental picture contains a set of hypothesized relationships between action by the decision-maker and events or outcomes in the environment. In other words, it constitutes his understanding of his environment, and it may be wrong or oversimplified. The next section of this chapter discusses this map. The third component of the cognitive element in Figure 7.1 is analogous to the cognitive map, but is specific to the organizational environment. This element puts constraints on policy also, the most important of which will be discussed below as "decision costs."

Together, the operational norms, cognitive element, and derivative emotions make up the attitude triangle of Figure 7.1. Together these elements are the direct precursor of action. The bulk of this chapter focuses on the mechanisms of the translation to policy. Before going into the cognitive map and policy selection discussions, one disclaimer must be stated. The analogy of many of these approach elements to psychological concepts developed for individuals cannot be overdrawn. The cognitive map we are interested in, for instance, is a kind of amalgam of those of many individuals, as are "emotions." The use of these concepts does not imply, however, a reification of decision making. This chapter,

FIGURE 7.1: CONCEPTUALIZATION OF AFFECTIVE-COGNITIVE-BEHAVIORAL LINKAGES



with considerable emphasis on organizational elements, should eliminate that misperception of this approach, if it exists.

B. The Cognitive Map

Because objective indicators will serve as surrogates for the perception of environmental conditions, that concept of the cognitive element needs no discussion. Our later discussion of decision costs will focus on the third cognitive element, the internal organization constraint perception. Here, then, we will look at the cognitive map only.

Cognitive maps serve two functions for decision-making which are important to us. First, they tell us what policies can affect the indicators which we wish to change. Second, they provide more specific information about interrelationships within the environment, an actual model of it, allowing an estimation as to how much policies must change to have the desired magnitude of impact on variables of concern. These two functions are closely related, and the first is in essence a special case of the second. They are separated here because the two functions pertain to two relatively distinct aspects of the decision process. The first determines the outcome of the search for an alternative set. The second assists decision-makers in selecting actual levels of action with policies. The separation of these two aspects of the process corresponds to two different types of constraints. The ability to recognize policy availability is one constraint. Herbert Hoover did not see fiscalist economic policies as potentially appropriate in the Great Depression, and it thus became impossible for him to adopt such policies, except accidentally. In contrast, Franklin Roosevelt knew the writings of Keynes and did have such policies in his "cognitive map." Exclusion from the cognitive map thus leads to exclusion of some theoretically useful policies from consideration. Other constraints apply to shape the actual degree to which policies are applied. Both information unavailability and concomitant uncertainty as to policy effects and organizational resistance prevented initial Keynesian policy applications by Roosevelt from being very bold.

One potential approach to the policy utility part of the cognitive map parallels that of indicator independence contribution representation. A five point scale running from zero (practically the same) to 4 (no relationship) with negative signs for inverse relationships was used at that time to judge the independence of contribution by indicators to values. This can be extended to relate indicators and policies in a matrix like Table 7.1. The depth to which a policy maker goes in his map when looking for relevant policies depends on the magnitude of the problem. A procedure for specifying the width of policy search will be presented later.

The second aspect of the cognitive map, the specification of relationships in the environment to the degree that specific <u>levels</u> of policy can be selected, presents a more complicated problem. This really calls for an entire simulation model of the environment, but one which incorporates the misperceptions and false hypotheses of the decision-makers. Instead of undertaking such a fore-boding task, the Mesarovic-Pestel model has in the past used the full-blown environmental simulation as the most reasonable substitute. This is especially reasonable given that many of the important errors made by decision-makers fall not into the category of degree of policy applied, but rather into the category of not recognizing policy availability at all--this type of error is incorporated through the first aspect of the cognitive map. Thus the Hoover administration would have "4"s linking fiscalist policies and economic recovery indicators. Even though our simulation of the environment might show their very effective use, Hoover would never try them. The Roosevelt administration would have perhaps a "2" or "3", but because of the severity of the situation in the Depression he would try the policies. As evidence of their success came in, the value might drop to "0" or "1". In a sense one could speak of "cognitive costs" associated with the use of a policy with a low (high-numbered) linkage. Once these costs are paid,

TABLE 7.1: POLICY RELEVANCE REPRESENTATION IN THE COGNITIVE MAP

	I 1	I 2	. . . .	In	P 1	P 2	. . . .	Pm
I 1	0	-1	4	3	2	--3	2	0
I 2		0	2	-2	4	3	3	2
: .			0	3	0	4	2	-2
. In				0	-1	4	-2	3
P 1					0	3	3	3
. P 2						0	2	-4
. P							0	-2
Pm								0

the policy remains available (unless unused, and then "forgetting" takes place and the costs must be paid again). Note that if we were simulating Roosevelt's application of fiscalist policies, we would have him use the total environmental simulation to evaluate the effectiveness of those policies. This does not mean, however, that he would use the policies to the full extent of their effectiveness as suggested by that model. Internal organizational constraints, including the absence of "perfect" information deny him that opportunity. The degree to which he will apply the policies will depend again on the severity of the situation, and will be one subject in the next section.

This second aspect of the cognitive map thus serves an important function in the policy search. That search is extremely complicated. If several policies are considered, and each of them offer a continuum of action levels, the possibilities are infinite, even within the organizationally constrained subset of alternatives. We could devise a random search procedure. A second alternative is to add one additional element to the cognitive map: a memory. If the decision-makers have some past experiences with policy application, then an initial policy mix can be selected from which further search can be conducted. Further search would still require the use of the full model as a surrogate for a mental model of complex relationships. Thus the memory can assist in this aspect of the cognitive map, but not serve alone. This experience memory could consist of a matrix with changes in policies related to resultant changes in indicator levels. This would require some sort of common scaling for cross-cell comparisons of policy strength. Change along the associated satisfaction scales could serve as such a common scale for the indicators; the associated decision costs of a policy, a concept to be presented below, could serve the same function for policies. Thus the experience memory would show the unit change in satisfaction per unit change in decision costs, for each policy related to each indicator, holding all other policies constant. In selecting a mix of policies, of course, all other policies are not constant and the interaction affects will weaken the policy search assistance capability of the experience memory.

This memory could, if desired, be made increasingly sophisticated. Forgetting could be represented by an exponetial decay function; higher order memory could include the recognition of patterns of problems and patterns of solutions. This latter sophistication might be highly desireable because the interaction affects of the policies in the basic experience memory will greatly weaken the potential contribution of that memory to the policy search.

C. The Behavioral Link--Decision Constraints

In rational actor models, the components of the procedure introduced thus far could produce a nearly "optimal" decision. National governments, however, like other organizations, do not act in optimal fashion. There are a number of constraints upon them, the most important of which are general lack of information, including uncertainty about policy impacts, and organizational resistance to change. It was a result of such constraints that Herbert Simon developed his concept of "bounded rationality." Simon said of his concept:[43]

> The principle of bounded rationality lies at the very core of organization theory, and at the core, as well, of any 'theory of action' that purports to treat of human behavior in complex situations.

There are many implications of bounded rationality for the decision-making process, of which three will be noted here.[44] First, problems are generally broken into quasi-independent parts, and decision-makers deal with these parts individually. Very often, parts are divided among organizational subunits. Thus there will almost inevitably be some factoring of solutions and some failure to select a well integrated set of politices to solve problems. The factoring of solutions can to some degree be overcome by strong central control over the subunits. Yet there will be many situations, such as that in the U.S.

defense department, where even a strong Office of the Secretary armed with tools like the Planning-Programming Budgetary System cannot overcome the separatism of the subsidiary units.[45]

Second, rather than maximizing or optimizing, decision-makers will satisfice. That is, rather than considering all alternatives, and choosing one calculated to produce the most desireable consequences, organizations will select action calculated to be "good enough." Organizations have some notion of what constitutes minimally acceptable performance, and resources devoted to decision-making beyond that level will seldom be committed. Another way of looking at this, although a viewpoint not endorsed by March and Simon, is that there is a stage beyond which costs of further alternative research and evaluation are greater than the expected benefits of improved action.[46] This is basically rational action, but is a rationality within the limits imposed by finite resources (including time) and abilities.

Third, decision-makers are working in an environment of uncertainty concerning the consequences of their actions, and will act in such a way as to minimize that uncertainty. One major implication of this has been developed by Lindblom:[47] In order to obtain feedback concerning the consequences of policy, decision-makers will act incrementally and frequently, rather than attempting to completely solve a problem with initial action. Also following from the tendency to avoid uncertainty, repertoires of action will be developed. This not only decreases the cost of alternative search, but it means that action consequences will be relatively predictable.[48]

Although cost-benefit analysis and organizational theory are generally contrasted and not compared, if we broaden our conceptualization of costs we can see the implications of bounded rationality flowing from the balancing of three types of costs:

1. Policy Search Costs
2. Decision Costs
3. Impact Costs

The most familiar type of costs, and the only one considered in traditional cost-benefit analyses is impact costs. This cost is directly comparable to the cost of <u>inaction</u> or the original dissatisfaction, because they both are environment based costs and both can be measured with the set of environmental monitor variables in the dissatisfaction function. For example, the problem which the decision-maker is trying to solve may be pollution of the air and water in his environment. As a result of efforts to bring indicators of that pollution within acceptable levels, other variables may be affected in undesireable ways, e.g. energy availability in the system. The decision-maker will become cognizant of the problem (assuming energy is monitored and included in the dissatisfaction function of affects variables like GRP which are). The balance which the decision-maker strikes between pollution and energy availability will depend on the operational norms generated in the normative layer of the model.

Strict cost and benefit analysis by decision-makers in terms of these impact costs is not possible because of the other two cost types. We have already introduced the basis for policy search costs. The connection between policies and target variables in the cognitive map vary from strong connections for the tried and tested policies, to weak connections for policies recommended by government commissions, academics, journalists, or "dreamers," to no connections. Paying search costs involves seeking additional information through detailed studies or most effectively through policy experimentation. The degree to which decision-makers will pay search costs depends directly on the level of impact costs. If the environmental situation looks bad, and policies with low search costs are projected to improve matters little, then the decision-maker will begin balancing search costs against impact costs.

The decision costs determine not which policies will be considered, but how much action can be taken on each policy. Decision costs include overcoming organizational structures and their vested policy interests, in general the use of power as a non-renewable resource, and the spending of money which reduces other policy options. To a degree decision costs are "instrument costs." The concept of instrument costs is not used here because the normal conceptualization of instrument costs crosscuts the three cost types discussed here. If policy-makers spend money to implement a program, that is an instrument cost. It involves impact costs in the transfer of money from those being taxed to those receiving it--costs which may not affect the original target only. For instance, the impact of taxing the general public for defense and the impact of giving the money to arms producing corporations are incidental to improving security. The spending of money on defense also has decision costs. Decision-makers will deprive themselves and other interests within the bureaucracy of that money for other policies, and power conflicts over how the money should be spent will have further costs, for instance in terms of future ability to prevail in such conflicts. Large decision costs then will again be paid only when the alternative is large impact costs. As search costs were balanced against impact costs, so will be decision costs.

These three types of costs are not normally distinguished. The reason is obvious: they are "soft," especially decision and search costs, and the distinctions among them are not always sharp. Anthony Downs has explored the process of alternative search and come up with the following analysis:[49]

> In search for alternatives, he starts with those he initially believes will yield him the highest net utility and works downward, evaluating them in relatively homogeneous sets in terms of their likely net utility as he sees it.....Therefore, he is more likely to include the following types of alternatives in each set he analyzes than he is their opposites, other things being equal:

---Those that provide ancillary 'side benefits' in terms of variables other than the ones whose drop from a satisfactory level caused him to initiate this intensive search.

---Those that are relatively simple and easy to comprehend.

---Those that involve marginal rather than major adjustments in the bureau's operations or structure.

---Those that do not depend upon estimations or consideration of highly uncertain variables, since such variables are difficult to use.

Note that all three of our cost types are involved in Downs's analysis. By "net utility" and "side benefits" Downs apparently means impact cost balancing. By simplicity of policies and their comprehensibility, as well as by avoiding uncertain variables, he is recogniaing search costs. By the emphasis on policies that "involve marginal rather than major adjustments" in organizational structure, he means decision costs. Clearly Downs wrote here not only about the selection of a set of policies for examination, but of the considerations involved in the actual choice of a policy; it is thus appropriate that all three cost types entered his discussion.

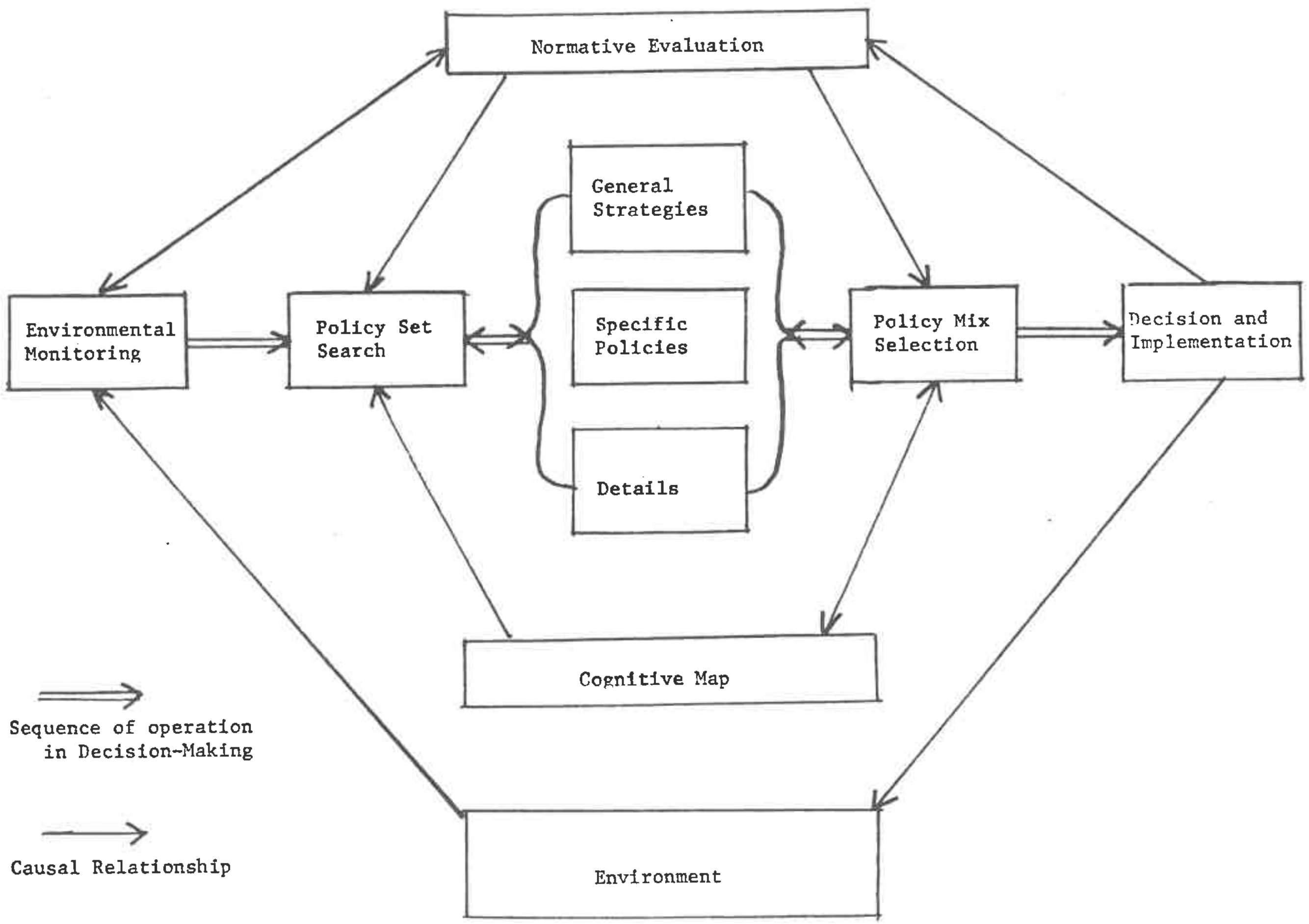
The reason for separating the cost types in the present typology is that there is no direct comparability of these costs, and if decisions are to be simulated, there must be. It is appropriate to talk in general about how decision and search cost factors constrain rational decision-making (or impact cost-benefit analysis) and lead to Satisficing and incremental policy making. (All references to Satisficing, or to related values of Satisfactory performance of Satisfaction will be capitalized here to aid in differentiation between these terms and those associated with the operational norm or satisfaction scales and the total satisfaction system indicator). But when we proceed to a general decision-making simulation, we must ask a number of questions. What is Satisfactory? How large will the increments be and when will they be larger or smaller? The next section will explain how we can develop an appropriately incremental and Satisficing model, through the introduction of these three cost types.

D. Policy Search and Evaluation

Figure 7.2 shows the basic sequence in any decision process. The first step is monitoring of the environment to see what problems exist and to evaluate the severity of them; in short to see the impact costs of inaction or present policies. This process also involves the projection of the environment insofar as the future interests decision-makers. The second step is a search for a policy set relevant to the problems discovered; both the evaluation of the situation and the cognitive map play important roles in the search. The third step centers on the search for, evaluation and selection of, an appropriate policy mix. The policy set selection and policy mix selection procedures are iterative as costs are balanced against each other and as the search proceeds from the most general strategies to the most specific details. The loop is finally exited with a decision and its implementation. This section will present details on one approach to the policy set search and policy mix selection iterative process and its culmination in a decision.

Selection of a policy set depends directly on the degree of dissatisfaction with the environmental situation and the linkages of the cognitive map. A decision-maker will focus on policies related to those indicators in the environment which pose particular problems. Which indicators and how many? One type of rule would be to look at any indicator below neither good, nor bad (NN) in satisfaction. But if all are above, some attention will still be directed at the lowest few, and if all are below, more will be judged critical, but not all. Thus a better rule could be to look at the bottom x% in terms of satisfaction, where x is a function of total system dissatisfaction. For instance, x might relate to the total satisfaction indicator as in this table:

FIGURE 7.2: ELEMENTS OF THE DECISION PROCESS



Total Satisfaction	X
VG	10
G	20
NN	30
B	40
VB	50

Given the focus on x% of all indicators, how large will the policy set be? The dissatisfaction with each indicator should determine the degree to which search costs will be paid in connection with that indicator. In terms of the linkages that were discussed above in the cognitive map between policies and indicators, only those linkages with very low numbers (where the policies have been tried and are known to work) will be considered if satisfaction is quite high. The following relationship between indicator satisfaction and acceptable cognitive costs might work:

Indicator Satisfaction	Acceptable Linkage
VG	0
G	0
NN	1
B	2
VB	3
VB-	4

Even when the situation is bad enough that high search costs will be borne, the first efforts of decision-makers will seek to avoid such payment. Thus the first policy set selected will include only 0 or 1 linkages. If Satisfaction can be achieved in terms of impact costs with this limited policy set, no further search will occur. If Satisfaction cannot be obtained, successive iterations will increase the examined policy set up to that limit suggested in the above table.

When the policy set is selected, either in the initial or any subsequent iterations, the next task involves developing an exact policy mix. Just as the search costs constrain the size of the policy set, decision costs constrain its boldness or its deviation from past policies. The last section introduced decision costs, but did not elaborate on their specification. Because decision costs include such highly complex factors as power augmentation or decrease, a subjective approach to its specification appears appropriate. The five point Likert-like scale used for operation norms provides one possibility for subjectively evaluating decision costs. Another, and probably more useful is a different five-point scale: negative, zero, low, medium, and high. Each policy available in the decision simulation would need have such a subjective scale associated with it. Generally, the zero costs level would match the current policy level. Even when present policy has monetary costs, the costs involved in bureaucratic struggles to reduce expenditures normally will outweigh or balance the benefit to any decision-maker of the additional discretionary funds derived from any cut-back. As with the operational norms there will frequently be physical and normative barriers to decision cost scale movement along the objective policy scale. Rules highly analogous to those for operational norm change would direct decision cost change. When policies are discrete rather than continuous, the decision scale values can still be used. For instance, an abortion law could be associated with one of the five scale values. Most often, even such seemingly discrete policies can best be scaled, such as abortion laws of various liberality. Again, either interactive setting by a given user or simulation by us of apparent scale values can be used.

Once the institutional or decision costs are established, procedures are needed for balancing those costs against impact costs. The table below suggests one balancing:

Indicator Dissatisfaction	Decision Costs
VG	Negative
G	Zero
NN	Low
B	Moderate
VB	High

As with search costs, the decision-maker will pay decision costs only as high as necessary to achieve Satisfaction. In his first trial he will look only at low costs. If these policies fail to produce an expectation of Satisfaction, he will move to higher cost levels, up to the maximum suggested in the above table.

Reference was made in discussions of both search and decision costs to attempts to achieve Satisfaction. Some criterion has to be used for Satisfaction. Until it is obtained, greater and greater search and decision costs will be tolerated up to the limits of such costs associated with the initial indicator level of satisfaction. If those limits are reached without Satisfaction, then the most nearly Satisfactory policy will be accepted--essentially then relaxing the Satisfaction criterion. Because Satisfaction should be dependent upon the initial condition of the environment, a logical criterion of Satisfaction might be: Satisfaction vis-a-vis policy selection will be obtained when the projected impact of the policies moves the objective indicator x% of the distance between its projected value without action and the very good level of the operational norm scale. An appropriate value for x may be about 20%. Thus if the value of the indicator is evaluated as "very bad" without action, our policy set and mix would be Satisfactory if we expect to raise it to "bad." If, however, the initial value were already "good," we would be Satisfied with a small movement towards "very good." Normally 20% change could not be expected in one year--the satisfaction function incorporates future years as well, however, so 20% change is not unreasonable. The actual percentage should be regionally dependent and a function of the degree of future planning. Using this approach, action would normally be taken on a problem the first year it was perceived. If that action rêsolved the problem the first year, it would not show up again. If the action were meant to solve the problem only with considerable time delays, further tinkering with the policy and further actions could occur.

E. The Heuristics of the Decision Search

The components and constraints of the decision process have now been laid out. We still need details on the procedure for looking at various policy mixes. Two heuristics will be outlined here. The first is simplest and will be in fact one component of the second.

The first step, as shown earlier in Figure 7.2 requires environmental monitoring. The full environmental model should be used to project forward the likely state of the environment, thus serving as a surrogate for a full-blown cognitive map. In this process, some percentage of all indicators, the problem indicators, are selected as described earlier. The initial selection of relevant policies from the cognitive map should be made, holding search costs down to "1." All policies applied regularly in past years should have zeros or ones associating them and the relevant indicators so that they are automatically incorporated into the policy set. The search for a policy mix begins with the old levels of policy application; remember, decision costs at those levels are close to zero. An initial new mix of policy is created within the constraints of low decision costs through the use of the experience memory. That memory tells us how much increased satisfaction we can get on each indicator and in the total satisfaction indicator with each decision cost unit of change in policy. The experience memory will have to be created at the beginning of the simulation by experimenting with each policy individually to see what impact this will have on each indicator. Periodically it will need be updated as the policy mix and environment changes.

This initial policy mix will not necessarily or even usually be the most satisfactory mix, even when the experience memory is newly created, because of the interaction affects between the policies. Thus a search pattern will begin around the initial mix and proceed until Satisfaction is obtained or until all constraint limits are reached. The pattern will begin by manipulating the policy which according to the experience memory has the most impact on total system satisfaction. Both downward manipulations toward lower decision costs and upward manipulations toward maximum acceptable decision costs can be tried. During each trial, total satisfaction will be calculated and increased satisfaction will be used as the criterion for acceptability of the new policy mix. When maximum satisfaction is obtained with the most useful policy, others will be manipulated in the same way in decreasing order of promise. After all policies are manipulated, the cycle can be tried again or accepted as a reasonably close estimate of the most nearly Satisfactory policy within the constraints of that policy set and the decision costs. If the policy set and mix are not Satisfactory, the cognitive map will be reexamined for a larger policy set, accepting the next higher level of search costs. The procedure discussed in this paragraph will then be repeated, using the mix discovered in the procedure as supplemented with the additional policies at most recent levels of application. The policy mix heuristic and extension of policy alternative procedures will continue until Satisfaction or outer constraints are reached.

This is a complicated procedure and one which will use much computer time for large simulations. A simpler and shorter total search heuristic would be desireable. One procedure for shortening the search is a higher order memory with pattern recognition. That would also more effectively deal with the progression from general strategies to specific policy details shown in Figure 7.2, but not really maintained in this search heuristic. Various environmental patterns of problems could be associated with various policy patterns or "general strategies." This is clearly not a simplification, but would shorten the search and improve the logic.

It would also be possible to avoid the gradual increase in the acceptable policy set and the many additional iterations that requires by initially accepting all policies with search costs less than or equal to the maximum permissible given the associated indicator dissatisfaction. A further simplication would be to lump the cognitive map element relating policies and indicators with the experience map. The relevance of policies can be judged from the experience map, in fact with interval rather than ordinal precision. This simplication should be resisted. The experience map is created from the total environmental model and thus represents the cognitive map of the simulators, not of actual decision-makers. Even using the simulation in the experience map formation misrepresents the real world, although necessarily. If the policy relevance portion of the cognitive map were also derived from the simulation, policies like the slaughtering of India's sacred cows would result. An effective descriptive simulation must avoid that simplification.

An alternative heuristic procedure develops the possible semi-institutional interpretation of the value and norms representation procedure which was discussed in Chapter 5. It assumes more conflict between the general values, corresponding to interdepartmental conflict for resources. This can be introduced by first establishing a desired policy set from the viewpoint of each general value, using the earlier heuristics. This corresponds to each department in a government submitting its budget request. These ideal policy sets or requests will conflict. The superior level of satisfaction or government can then reconcile the lower levels. The first step might involve setting new policy levels at compromise values, perhaps weighting the compromise in favor of those values on which lowest total satisfaction was computed in the initial "request." From this initial policy set at the central level, a procedure like that described above could be used in a search for the most satisfactory policy set in terms of the central decision-maker or total satisfaction function. It is difficult to predict how different the policy implications of the two approaches would be.

F. Optimizing

The above procedures were developed to serve in descriptive and not optimizing simulations. Actually, it is quite difficult to optimize in the kind of non-linear simulation to which this approach might be applied. The very complex function of total satisfaction over all the policy alternatives could not easily be searched for peaks. But if one wants to remove the search and decision costs from the decision procedure, a relatively optimizing approach can be developed. One must set all decision costs to 0, set all linkages in the policy relevance part of the cognitive map to 0, develop extensive pattern learning, and leave out any forgetting.

This variation of model use makes possible the pattern of uses shown in Figure 7.3. If the operational norms of the system are meant to be those of the actual political unit and the decision procedure is Satisficing, the overall mode is descriptive. Present policy should be duplicated and a reasonable projecting of future possibilities is the target. If norms are supplied by the interactor (as his own) and the basically "optimizing" procedure is used, the overall mode of operation is "optimizing." The two cells on the other diagonal can be termed "What if?" cells. In one case, "what if" present societal and policy norms were not constrained by the decision situation; in the other case, "what if" the interactor's norms were guiding a realistic policy process? All four modes of operation have utility for simulators and should be maintained options.

FIGURE 7.3: MODES OF MODEL USE

Decision Procedure	Norms Supplier: Interactor	Norms Supplier: Describer
"Optimizing"	"Optimizing"	What if?
Satisficing	What if?	Description

8. Concluding Comment

Many of the proposals in this report may only be testable in a working model, and a prototype is the next priority. In the building of a prototype, certain procedures may be found to be unworkable or undesirable. Thus work on the prototype should remain flexible. I have made, however, a sincere effort to present an overall perspective on Project UTOPIA that can work and can do what it should. The problem is too complex to expect completely satisfactory or optimal solutions. Hopefully the constraints of my own time and talents have not led me to Satisfice too far from the optimal.

FOOTNOTES

[1]There are massive political science and organizational literatures. See Barry B. Hughes, "Computer Simulation of Political Decision-Making: A General Approach and Prototype," Case Western Reserve University, March, 1974, mimeo.

[2]M. Mesarovic and E. Pestel, "A Goal-Seeking and Regionalized Model for Analysis of Critical World Relationships--The Conceptual Foundation," Kybernetes Journal, Vol. 1, 1972.

[3]This project has had no official title in the past. The Project UTOPIA label seems quite appropriate. This writer also suggested for consideration the title, Computerized Norms and Their Relation to Our Lives (CONTROL). With a marked absence of sense of humor, Dr. Bossel flatly rejected this second suggestion. For an earlier description of project activities, see Hartmut Bossel, "Notes on the Simulation of the Norms Stratum and Norms Adjustment for Multi-Echelon Processes," Institut fuer Systemtechnik und Innovationsforschung, Karlsruhe, Germany, February, 1973, and Hartmut Bossel and Barry Hughes, "Simulation of Value-Controlled Decision-Making: Approach and Prototype," same institute, December, 1973.

[4]I am indebted to Martin Jaeckel, "Some General Considerations on Societal Values and Policies," Project UTOPIA paper, April, 1974, for this definition, in the discussions of Parsons which follow, and in the later discussion of Nicholas Rescher's work. See Talcott Parsons, The Social System (New York: Free Press, 1951), p. 386.

[5]See Talcott Parsons and Edward Shils, ed., Toward a General Theory of Action New York: Harper Torchbooks, 1962).

[6]Systems of Political Science (Englewood Cliffs: Prentice-Hall, Inc. 1968, p. 32).

[7]Amitai Etzioni, The Active Society (New York: The Free Press, 1968), p.623).

[8]Ibid., pp. 624-25.

[9]Pitirim Sorokin, Social and Cultural Dynamics (New York: American Book Co., 1937), p. 73.

[10]Abraham Maslow, Motivation and Personality, second ed. (New York: Harper and Row, 1970), pp. 35-47.

[11]Etzioni, op. cit., p. 657, footnote 11; see also the motivational system and end values categories of Clare Graves, "Human Nature Prepares for a Momentous Leap," The Futurist (VIII, #2), April, 1974, pp. 72-87.

[12]Albert K. Cohen, Deviance and Control (Englewood Cliffs, N.J.: Prentice-Hall, 1966), p. 60.

FOOTNOTES (CONTINUED)

[13]Maslow, *op. cit.*, p. 53.

[14]See the bibliographies in Harry C. Triandis, *Attitude and Attitude Change* (New York: John Wiley, 1971) and Rolf Oerter, *Struktur and Wandlung von Werthaltungen* (Muenchen: R. Oldenbourg Verlag, 1970).

[15]See, for example, Jerome B. Kernan and George G. Trebbi, Jr., "Attitude Dynamics as a Hierarchical Structure," *The Journal of Social Psychology*, 89, 1973, pp. 193-202.

[16]Nicholas Rescher, *Introduction to Value Theory* (Englewood Cliffs: Prentice-Hall, 1969); again I am indebted to Jaeckel, *op. cit.* for his discussion of Rescher.

[17]*Ibid.*, p. 9.

[18]Nicholas Rescher, "What is Value Change? A Framework for Research," in Kurt Baier and Nicholas Rescher, eds., *Values and the Future* (New York: The Free Press, 1969), pp. 68-109).

[19]See also the discussion of value change in Bossel and Hughes, *op. cit.*

[20]Harvard University Program on Technology and Society, Research Review No. 3, Cambridge, Mass., 1969.

[21]*Competing Paradigms in Prescriptive Theory*, Ph.D. dissertation draft, Case Western Reserve Political Science Department, May, 1974

[22]"Comment," in Abraham Maslow, ed., *New Knowledge in Human Values* (Chicago: Henry Regnery Co., 1959), pp. 199-223.

[23]*Ibid.*, p. 211.

[24]*Ibid.*, p. 218; Weisskopf quotes from Paul Tillich.

[25]Those who are interested in these literatures would do well to receive the *Social Indicators Newsletter* of the Social Sicence Research Council Center for Coordination of Research on Social Indicators. The issue of May, 1974, for example, included a discussion of the U.S. Office of Management and Budget's *Social Indicators 1973* (Washington, G.P.O., 1974), and articles on social indicator projects in Great Britain, France, Scandinavia, Germany, and Japan.

[26]Leslie D. Wilcox, Ralph M. Brooks, George M. Beel, Gerald E. Klonglan, *Social Indicators and Societal Monitoring* (San Francisco: Jossey-Bass, Inc., 1972).

[27]Norman C. Dalkey, with Daniel L. Rourke, Ralph Lewis, and David Snyder, *Studies in the Quality of Life* (Lexington, Mass.: D. C. Heath. 1972).

FOOTNOTES (CONTINUED)

[28]Research Memorandum EPRC-6747-2, February, 1969.

[29]See HEW, Toward a Social Report, 1969.

[30]Stanford Research Institute, *op. cit.*, p. 22.

[31]New Brunswick, New Jersey: Rutgers University Press, 1965.

[32]New Haven: Yale University Press, 1972

[33]Geoffrey Vickers, "Values, Norms, and Policies," Policy Science 4 (1973), p. 103 f.

[34]For this breakdown, see D. Katz and E. Stotland, "A Preliminary Statement to Theory of Attitude Structure and Change," in S. Koch, ed., Psychology: A Study of Science (New York: McGraw-Hill, 1959).

[35]Maslow, *op. cit.*, pp. 53-54.

[36]Etzioni, *op. cit.*, p. 297.

[37]Bossel and Hughes, *op. cit.*

[38]Similar curves are discussed in the Rand study, Dalkey, *et. al.*, *op. cit.*, p. 95.

[39]Triandis, *op. cit.*, pp. 42-44.

[40]Rescher, *op. cit.*, p. 76.

[41]Eleanor Bernet Sheldon and Kenneth C. Land, "Social Reporting for the 1970s," Policy Science 3 (1972), p. 140.

[42]Edward C. Tolman, "Cognitive Maps in Rats and Man," Psychological Review, 1948, 55, pp. 189-208.

[43]Herbert A. Simon, Models of Man (New York: Wiley, 1957), p. 200.

[44]See also Graham T. Allison, Essence of Decision (Boston: Little, Brown, 1971), pp. 71-72.

[45]Alain C. Enthoven and K. Wayne Smith, How Much is Enough? (New York: Harper and Row, 1971.

[46]James G. March and Herbert A. Simon, Organizations (New York: Wiley, 1958), p. 141.

FOOTNOTES (CONTINUED)

47 Charles E. Lindblom, "The Science of Muddling Through," Public Administrative Review, Vol. XIX, No. 2 (Spring, 1959), pp. 79-88.

48 March and Simon, op. cit., p. 173.

49 Anthony Downs, Inside Bureaucracy (Boston: Little, Brown, 1967), p. 170.

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VI.3. AN INTERACTIVE DECISION STRATUM FOR THE MULTILEVEL WORLD MODEL

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April 1974

AN INTERACTIVE DECISION STRATUM FOR THE MULTILEVEL WORLD MODEL

M. Mesarovic, B. Hughes, T. Shook, R. Pestel, P. Gille, S. Yoshii

A world model being developed by the authors for the Club of Rome is described. It is based on an interaction between man—the decision maker or the policy analyst—and the computer. Such a symbiosis avoids the pitfalls of relying solely on the computer for policy analysis, which by necessity leads to a mechanistic view of the situation; it provides also means for a creative use of computer techniques for extending the logical capability of man in long-term planning and analysis while leaving the ultimate responsibility for prediction, planning and decision making in his hands. The model is multilevel and hierarchical, with the world represented not as an aggregate, but as a number of regions with countries grouped according to economic similarity.

A WORLD model* is being developed for use as a *practical decision tool* by both decision makers and policy analysts. The key feature of this multilevel, hierarchical, regionalised world (M-P) model is the use of the interactive mode in which man and computer work as partners in analysing the decision situation, each assuming the role assigned so as to use the capabilities of both most advantageously. In such an operation the analysis is the outcome of both the logical and computing capabilities of the machine on the one hand and the intuition, experience and heuristic capability of man on the other. This approach is fully consistent with the major aim of the M-P world model which asks for the representation of decision-making and goal-seeking processes: a practical way to implement such a model is by an interactive mode of operation. This permits evaluation and assessment of intangibles such as technical innovation, discoveries, new and unexpected substitution possibilities, the effect of reduced diversity in the cultural ecosystem, and above all the social, political, and psychological developments.

* The work described in this article is a part of the project "Strategy for Survival" (see "An alternative strategy for the Club of Rome" in this issue, page 421) directed by M. Mesarovic, Professor and Director, Case Western Research University, Systems Research Center, Cleveland, Ohio, USA, and by E. Pestel, Professor and Director, Technical University, Hannover, W. Germany. B. Hughes, T. Shook and S. Yoshii are at the Case Western Reserve University, R. Pestel and P. Gille are at the Medizinische Höchschule, Hannover, W. Germany.

The computer contains a representation of dynamic processes relevant for the situation (problem) of concern, the alternatives available to the decision maker for affecting the situation, and the constraints which he must observe in implementation. The decision maker observes changes during the evolution of the system in time (*via* an appropriate set of indicators) and by using his judgement determines when a corrective action is called for. Depending upon the specific aspects of the undesirable behaviour, the decision maker asks the computer for more detailed information on the situation, the type of policy alternatives, strategies and measures available, the constraints to be observed, etc. He then makes appropriate decisions and instructs the computer accordingly. As a rule, the interaction between the decision maker and the computer is more complicated, involving numerous iterations before a final set of decisions is made. However, the basic division of labour between man and machine is always the same: *man* decides on *values*, *priorities*, *costs* and the *level of risks to be taken;* the *computer* indicates the *breadth of choices* and *likely consequences*.

The energy crisis has been selected for the first implementation of the decision stratum of the M-P world model because of the paramount importance which energy plays in all aspects of the world system, and because of the real concern which exists in many parts of the world about the possibility of a crisis occurring in the near future. In this article we describe the use of the model for the decision analysis of the energy crisis in the developed world—one of the 10 regions of the world incorporated in the model at present. When the model is developed fully each region will contain a representation of its own decision processes.

The decision process represented in this model occurs under the condition of a crisis situation. This has its roots in the very basic structure of the M-P world model which has three levels of system's representation determined in reference to the system behaviour under different extreme conditions[1]: namely, the first, causal, stratum embodying all normal processes which by and large, if left alone, will be a continuation of historical trends; the second, organisational, stratum represents the response of the societal institutions to the crisis situations while the third, normative, stratum determines goals, objectives, and values which govern the organisational stratum at any particular point in time. The present demonstration is but an illustration of implementation of such a multilevel world system model.

A distinctive feature of a crisis situation is its time period: short-term, usually in the 1 to 3 years range; intermediate, 3 to 10 years; and long-term, over 10 years. We shall consider the case of a medium-term crisis here. Although our concern in principle is with long-term development, the events surrounding an intermediate crisis are much easier to describe in familiar terms and on the basis of more reliable data. The interactive mode analysis can therefore be more easily assessed.

Basic structure of the interactive policy analysis system

The basic physical components are the interactor and the computer (Figure 1). The computer contains a programme which has two levels or strata: the *decision stratum* and the *causal stratum* (Figure 2).

The decision stratum models various functions performed in the process of arriving at a decision and the conditions and constraints under which the

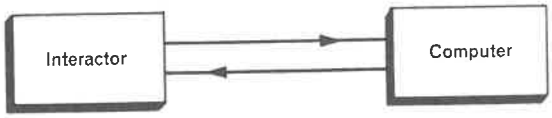

Figure 1

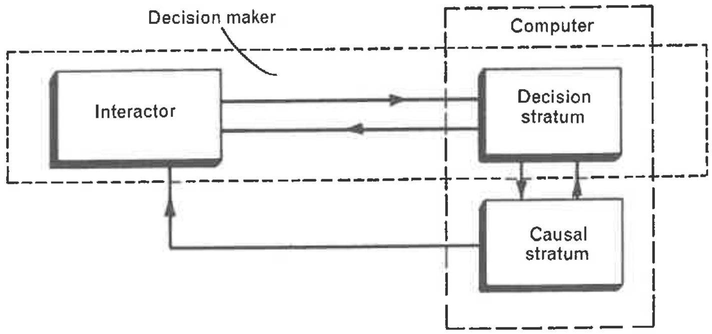

Figure 2

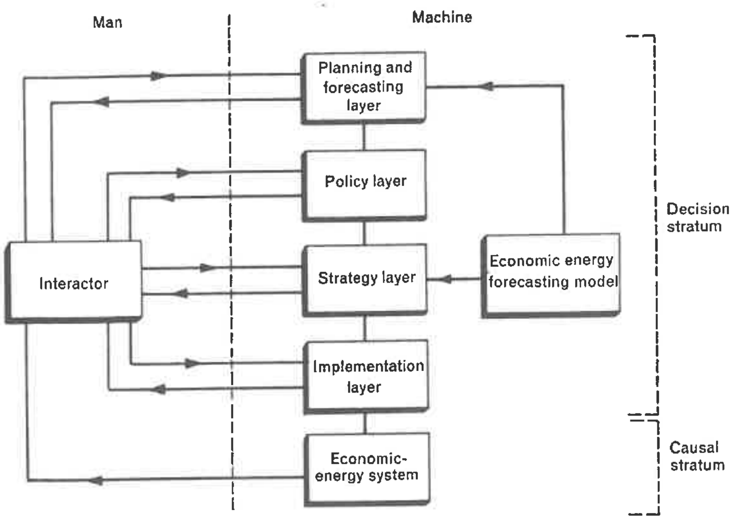

Figure 3

decisions are made. The interactor together with the decision stratum programme represent the decision-making part of the system.

The causal stratum represents the model of the regional economy and the basic energy relationships. A more detailed description of this model is given in the Appendix. Briefly, the economy is represented in terms of four sectors: agriculture, minerals and energy, industry, and services. In its second version now being completed, the economic model has nine sectors including specifically the construction of residential dwellings, transportation and health services. The model reproduces the evolution of the basic economic processes and functions of the economy over time: production, consumption (government and public), export-import, capital formation, input needs, etc. The energy relationships give the supply and demand of energy as well as inter-regional imports and exports. The behaviour and performance of the economy is described in terms of a large set of appropriate economic indicators. The causal stratum also contains a model of population growth designed only to indicate the level of population at any particular time and as needed in the decision process, rather than giving a more detailed demographic description of the region.

The decision stratum contains four levels, termed decision layers or simply layers, as indicated in Figure 3—the *planning and forecasting* layer, the *policy* layer, the *strategy* layer, and the *implementation* layer. Each of the layers is assigned a specific role, and their functions are arranged in a hierarchy: the higher layers' functions are broader and concerned with longer time periods. The lower layers' functions are more technical and concerned with more immediate objectives. The final decision is the result of a coordinated response of all layers.

The planning and forecasting layer is responsible for anticipating future needs and possibilities as well as indicating the set of alternative courses of events which could affect future development. It sets the stage for policy considerations. For example, in an energy model it indicates the possible increase in energy production cost over an appropriate time period as a possible area of critical problems.

The policy layer is responsible for the broad decisions formulated in reference to political and social expectations and possibilities. For instance, in the case of an energy shortage the overall policy can be to restore the abundance of energy with all other considerations taking second place; or it can be to work on curtailing consumption and preserving energy resources; or it can be to make whatever adjustments are necessary to limit the dependence on imports from some or all other regions.

The strategy layer is responsible for finding the strategy to carry on the selected policy. For example, if the overall policy is generally to make available as much energy as possible, one strategy can be to shift the investment from the industrial sector, while another can be to transfer the investment from the service sector as well.

Finally, the implementation layer is responsible for determining the exact magnitudes of changes needed for implementation. For example, if the strategy is to shift 40% and 60% of the investment from the industrial and service sector respectively, then the implementation layer determines the exact value of investment needed, its effect on other investments, on imports, etc.

In order to evaluate alternative policies and strategies as well as to assess the impact of alternative developments, it is necessary to have a simplified model of the basic economic-energy relationships. Such a model is provided as a sub-routine and can be used on any one of the decision layers.

To illustrate the process of using the system as a decision-making tool, the time sequence of a typical man-machine interaction is given in Figure 4.

Rules for the interactive mode operation

Conversational rules. The interactor communicates with the machine by means of words constructed from a given alphabet using the appropriate grammar. An example of the alphabet and grammar is described later.

The interactor should use words which are both properly constructed and are appropriate to the stage of the decision process. One type of mistake he can make is to use a word which is not in the dictionary. He might also use inappropriate words. For example, he might use a word which denotes a request for additional information on a specific strategy before even the general policy has been selected. If the interactor makes a mistake by communicating a word which is illegal by construction or at the stage of the decision process, the computer instructs the interactor about the mistake and indicates the type of mistake made.

The interactor has two basic classes of inputs: *requesting* and *instructing*. The request inputs are of different kinds depending on both the stage in the decision process and the format in which the information is to be presented. They also might refer to the set of policy alternatives or strategies available. The instruct inputs are primarily decisions on policies, strategies, parameters, on implementation, or on return to a previous stage for additional considerations.

The computer responds by statements in English and with desired data, mathematical relationships, or graphs. A special effort is made to present the computer outputs in the most usable form; indeed no special instruction is necessary to read and understand the printouts, the only requirement being an understanding of the problems and issues involved and of the indicators and variables of importance.

The interactor follows a conversation like the one shown in Figure 4. He can construct his own sequence which of course must be internally consistent.

Communication language. To facilitate communication with the machine an appropriate language for inputing the information into the computer is needed. Such a language is designed so as to be simple for inputing while at the same time containing sufficient elements to convey the meaning to the interactor at least in one of the natural languages.

We shall present here the simplest possible version of such a language which however is sufficient for the analysis of some important long-term policy decisions. In such a simple form the language is nothing but a code.

An alphabet consists of a set of symbols (in our case primarily a subset of the upper case letters from the English alphabet). A word is a string of symbols from the alphabet constructed according to the rules of grammar. We shall describe these rules informally in reference to the meaning of each symbol for the specific model under consideration. In view of the simplicity of the language

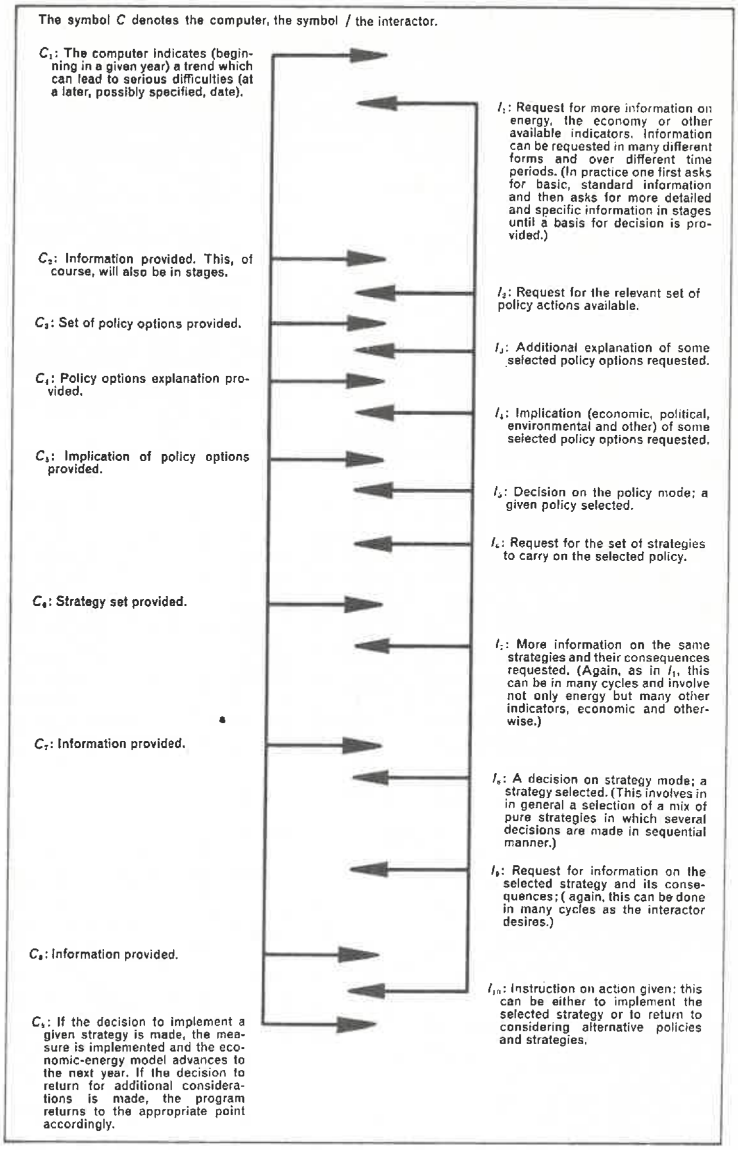

Figure 4. Time sequence of events in man–computer interaction

TABLE 1. DICTIONARY OF "COMPUTER INPUT CODING"

PD1	Policy Decision No. 1	GTP	General economic Tables, Predicted
PD4	Policy Decision No. 4	GTH	General economic Tables, Historical
PYD	Policy, Years to be applied	GGR	General economic Graphs, Reference
PE1	Policy, Explanation of No. 1	GGP	General economic Graphs, Predicted
PE4	Policy, Explanation of No. 4	GGH	General economic Graphs, Historical
PI1	Policy, Implications of No. 1	PES	Policy, Explanation of Strategy
PI4	Policy, Implications of No. 4	PEV	Policy, Explanation of Variables
PTR	Policy, Tables of information on Reference values	EEV	Economy, Explanation of Variables
PTP	— on Predicted values	GEV	General economic information, Explanation of Variables
PTH	— on Historical values	PYS	Policy Year, Status of energy and economic indicators
PGR	Policy, Graphs of information on Reference values		
PGP	— on Predicted values	*Further explanations*	
PGH	— on Historical values	?	Headings in the next step in decision process
ETR	Economy, Tables of information on Reference values	GO	Advance to next step
ETP	— on Predicted values	TOP	Restart at 1970
ETH	— on Historical values	NEW	Graphs of the history up-to-date + TOP
EGR	Economy, Graphs of information on Reference values	HEL	List of command words
EGP	— on Predicted values	END	Graphs of the history up-to-date + End of Run
EGH	— on Historical values		
GTR	General economic Tables, Reference	BYE	End of Run

we shall directly refer to a dictionary of words, some of which are given in Table 1.

The words which refer to the model in terms of the corresponding part or function of the real system are in the first block in Table 1. The second block in Table 1 contains some special words which have a direct meaning for the computer operation of the system. The words in the first block follow basically the following rules: the first symbol in each word refers to the layer in the decision stratum model; the second symbol is a legal word which denotes the format desired as indicated in Table 1, eg T for table, G for graph, etc; the third letter indicates the time period and condition under which the information is needed; eg R for reference values, P for predicted values, etc.

An example of the interactive policy analysis

In order to illustrate the possibilities provided by the interactive model a complete printout of the policy analysis and decision process spanning over a 10-year period is given in Figure 5. To facilitate understanding of the structure of the printout each inputing time is indicated by an arrow (I_1, I_2, etc) and the computer's response is indicated by a square bracket (C_1, C_2, etc).

This example of the interactive mode is far from indicating all the flexibility of the approach. However, it does illustrate what kind of process and interaction is involved, helping in this way to clarify sharp distinction between this type of approach and the classical deterministic computer simulation methods. Also the format of the interaction can be designed to suit the desires of the interactor, eg, it might be preferable to have the information presented in a graph form rather than as tables.

The system as developed so far can be used in a number of actual decision-making situations or for demonstration purposes. For example, it is possible

I_1: Interactor requests information appropriate for the stage of the decision process, by a blank space as the input.
C_1: A set of sources of potential problems is indicated as well as the present year.
I_2: Additional information is requested regarding the anticipated source of problems as of the current state of affairs.
C_2: Since an increase in the cost of energy production is anticipated by the forecasting layer the information on the anticipated values of some basic energy indicators is given for two cases: (1) Reference case, when the production cost does not increase; (2) Case when the production cost is increased by 5%. The information is provided in a tabular form for 1 (3, 5) and 10 years ahead.

Next interaction, indicated by the sign ! shows the response of the computer to a use of an invalid word.
I_3: Having necessary information as to the possible course of events in the future the interactor requests the set of policies available for the type of problems anticipated (eg, increase in the production cost).
C_3: The set of requested policies is provided.
I_4: In the judgement of the interactor the policy 2 appears to have promise and an explanation of that policy option is requested by using the word PE2 from the dictionary.
C_4: The requested explanation provided.
I_5: The explanation of the policy 2 does not seem to meet the expectations and the interactor would like to have a more detailed explanation of another policy, namely policy 1. The input word PE1 is used.
C_5: The requested explanation provided.
I_6: Overall, policy 2 seems to be preferable but before a final decision is made the implications of applying the policy could be of considerable help. Appropriate information is requested by using the word PI2.
C_6: Information on the implication of the policy 2 provided.
I_7: Decision on the policy options is made; the policy 2 is selected and the computer instructed accordingly by using the word PD2.
C_7: Set of strategies available for the implementation of policy 2 provided and the interactor is requested to select one of them.
I_8: Selection of a strategy is indicated, namely strategy 1, by using the word 1.
C_8: The interactor is requested to decide on the parameters which will specifically determine a unique measure for implementation. In this case a shift in the source of investment between the industry and services is indicated.
I_9: The interactor selects 30 versus 70% split between the investment portion to be transferred from the industry and the services respectively.
C_9: The amount of the required investment is given in absolute rather than relative terms. Notice a major switch in the role between the interactor and computer in the steps I_7–C_9; in effect, during this stage the computer asks the questions and provokes a response from the interactor.

Figure 5. Computer printout from demonstration of M-P world model applied to energy problems in the developed countries economic sector over a 10-year period, 1970–1980. (To save space some of the data for intermediate years have been omitted.)

```
*** M-P WORLD MODEL DEMONSTRATION ***
        - ECONOMIC SECTOR -
      - DEVELOPED COUNTRIES -

  CRISIS MONITORING IN THE ENERGY SECTOR

READY-0  <---- I1
  POTENTIAL PROBLEMS IN THE ENERGY SECTOR ARE                                  ]
     1. LIMITED AVAILABILITY OF IMPORTS                                        ]
     2. RESOURCE SCARCITY PRESSURE ON COSTS                                    ] C1
     3. PRESSURES ON COSTS THROUGH MEASURES FOR ENVIRONMENTAL PROTECTION       ]
     4. INCREASING ENERGY DEMAND                                               ]
     5. TOO SLOW A TECHNOLOGICAL DEVELOPMENT                                   ]

  THIS IS YEAR 1970
READY-1  <---- I2
-CASE 1          - NO COST INCREASE -                                          ]
 YEAR    REFPC     RECPC        RIM       RIM/REC                              ]
 [illegible]
 1980    4.911     7.292      1992.621    0.327                                ] C2
-CASE 2  -COST OF ENERGY PRODUCTION INCREASED BY 5 PER CENT-                   ]
 YEAR     EPPC      ECPC        IM        IM/EC                                ]
 1970    3.562     5.931      1792.364    0.399                                ]
 1980    4.658     7.264      2180.313    0.359                                ]
READY-2          ]
GTPG             ] !
INVALID CODE. TRY AGAIN.
READY-2  <---- I3
  AVAILABLE ENERGY POLICIES:                                                   ]
     1. INCREASE IMPORTS                                                       ]
     2. INCREASE ENERGY PRODUCTION BY INVESTMENT SHIFT                         ] C3
     3. INCREASE ENERGY PRODUCTION BY INVESTMENT INCREASES                     ]
     4. APPLY MIXED POLICY OF INVESTMENT AND IMPORTS                           ]
READY-3  <---- I4
PE2
    EXPLANATION OF POLICIES
  2. INCREASED ENERGY PRODUCTION BY INVESTMENT SHIFT.                          ]
    ENERGY NEEDS ARE SATISFIED BY INVESTMENT SHIFTED TO THE ENERGY SECTOR      ]
    FROM OTHER SECTORS OF THE ECONOMY, SUCH AS INDUSTRY OR SERVICES.           ] C4
    (THIS COULD BE EFFECTED BY OIL DEPLETION ALLOWENCES OR OTHER TAX           ]
    TOTAL INVESTMENT IS NOT INCREASED.                            BENEFITS).   ]
READY-3  <---- I5
PE1
    EXPLANATION OF POLICIES
  1. INCREASED IMPORTS.                                                        ]
    ENERGY NEEDS ARE SATISFIED BY INCREASED IMPORTS.                           ] C5
    THIS POLICY DOES NOT INTERFERE WITH THE ECONOMY.                           ]
READY-3  <---- I6
PI2
    IMPLICATIONS OF POLICIES
  2. INCREASED ENERGY PRODUCTION BY INVESTMENT SHIFT.                          ]
    INVESTING LESS INTO INDUSTRY AND SERVICES SLOWS DOWN ECONOMIC GROWTH,      ] C6
    WHICH IN TURN RELAXES THE DEMAND FOR ENERGY.                               ]
READY-3  <---- I7
PD2
  THE FOLLOWING STRATEGIES ARE AVAILABLE WITHIN THE POLICIES IN PARENTHESES    ]
  1. EPPC = REPPC AND IM/EC < RIM/REC (2,4)                                    ] C7
  2. EPPC < REPPC AND IM/EC = RIM/REC (2,4)                                    ]
  3. OTHER EPPC (4)                                                            ]
CHOOSE A STRATEGY (1,2,3)
1  <---- I8
SELECT DESIRED PERCENTAGE OF INVESTMENT SHIFT FROM INDUSTRY (E.G.,30).         ] C8
THE REST WILL COME FROM SERVICES.                                              ]
30 <---- I9
   POLICY 2 SELECTED.     20.514  BILLION ADDITIONAL DOLLARS INVESTED          ] C9
READY-4  <---- I10
   PREDICTED RESULTS OF POLICY:
   YEAR     EPPC     REPPC      ECPC      RECPC        IM         RIM          ]
   1971    3.[illegible]   3.[illegible]    6.348     6.077    1803.007   1825.307     ]
   1980    [illegible]   4.911     7.243     7.292     750.566   1992.621     ]
                                                                               ] C10
   YEAR     YIPC     RYIPC      YSPC      RYSPC       GRP        RGRP         ]
   1971    0.868    0.879     2.947     0.951     1541.642   1549.078     ]
   1980    1.000    1.054     1.075     1.114     2020.129   2033.876     ]
```

Explanation of variables:
EPPC = value of energy production *per capita* (in 1000 coal-ton equivalents)
ECPC = value of energy consumption *per capita*
IM = value of energy imports
IM/EC = value of imports to consumption ratio
R means reference value: no energy problems exist to increase production costs

```
C11 [ READY-5 <-- I11
      PYD1
         THIS IS YEAR 1971.

      READY-1 <-- I12
    [ -CASE 1              - NO COST INCREASE -

       YEAR     REPPC     RECPC        RIM       RIM/REC
       1971     3.690     6.077      1825.307     0.393
       1981     5.050     7.407      1990.195     0.318
C12
      -CASE 2  -COST OF ENERGY PRODUCTION INCREASED BY 5 PER CENT-

       YEAR     EPPC      ECPC         IM         IM/EC
       1971     3.690     6.048      1803.008     0.390
    [  1981     4.654     7.346      2273.452     0.366

      READY-2 <-- I13
    [     AVAILABLE ENERGY POLICIES:
             1. INCREASE IMPORTS
C13          2. INCREASE ENERGY PRODUCTION BY INVESTMENT SHIFT
             3. INCREASE ENERGY PRODUCTION BY INVESTMENT INCREASES
    [        4. APPLY MIXED POLICY OF INVESTMENT AND IMPORTS

      READY-3 <-- I14
      PD1
C14 [     POLICY 1 SELECTED.      0.0   BILLION ADDITIONAL DOLLARS INVESTED
      READY-4 <-- I15
    [     PREDICTED RESULTS OF POLICY:

          YEAR    EPPC     REPPC     ECPC     RECPC       IM         RIM
          1972    3.614    3.820     6.194    6.229    1993.191   1861.181
          1981    4.654    5.050     7.346    7.407    2273.952   1990.195
C15
          YEAR    YIPC     RYIPC     YSPC     RYSPC      GRP        RGRP
          1972    0.894    0.897     0.973    0.973    1595.272   1604.333
    [     1981    1.068    1.071     1.129    1.128    2060.487   2085.433

      READY-5 <-- I16
      PYD3
          THIS IS YEAR 1972
    [
          POLICY 1 SELECTED.      0.0   BILLION ADDITIONAL DOLLARS INVESTED
          THIS IS YEAR 1974

      ENERGY DATA OR GRP DATA FOR THE ACTUAL POLICIES IMPLEMENTED (HISTORY)
      (TABLES/GRAPHS) --- PTH, PGH, - GTH, GGH
C16       YEAR    EPPC     REPPC     ECPC     RECPC       IM         RIM
          1971    3.690    3.690     6.048    6.077    1803.007   1825.307
          1974    3.462    4.086     6.442    6.518    2150.687   1918.099

          YEAR    YIPC     RYIPC     YSPC     RYSPC      GRP        RGRP
          1971    0.868    0.874     0.947    0.951    1541.642   1549.078
    [     1974    0.939    0.940     1.016    1.012    1693.659   1713.486

          THIS IS YEAR 1974

      READY-1 <-- I17
      PD43
    [     CAPITAL INVESTMENT REQUIRED FOR STRATEGIES 1 AND 2 IS:
C17
              1.   110.968     2.   160.363
    [
       SPECIFY AN INVESTMENT LEVEL

      40.  <-- I18
C18 [ SELECT DESIRED PERCENTAGE OF INVESTMENT SHIFT FROM INDUSTRY AND SERVICES
                                                                      (E.G.3040).
      3040 <-- I19
C19 [     POLICY 4 SELECTED.   40.000 BILLION ADDITIONAL DOLLARS INVESTED
      READY-4 <-- I20
      PYD6
    [     THIS IS YEAR 1975

          POLICY 4 SELECTED.   40.000 BILLION ADDITIONAL DOLLARS INVESTED
          THIS IS YEAR 1980

      ENERGY DATA OR GRP DATA FOR THE ACTUAL POLICIES IMPLEMENTED (HISTORY)
      (TABLES/GRAPHS) --- PTH, PGH, - GTH, GGH
          YEAR    EPPC     REPPC     ECPC     RECPC       IM         RIM
          1974    3.462    4.086     6.442    6.518    2350.687   1918.099
C20       1975    3.666    4.221     6.543    6.657    2291.692   1940.776
          1980    4.137    4.911     7.037    7.292    2426.864   1992.621

          YEAR    YIPC     RYIPC     YSPC     RYSPC      GRP        RGRP
          1974    0.939    0.940     1.016    1.012    1693.659   1713.486
          1975    0.946    0.961     1.031    1.031    1737.521   1767.820
          1980    1.008    1.054     1.106    1.114    1962.648   2033.876

    [     THIS IS YEAR 1980
      READY-1
      BYE
```

I_{10}: Additional information on the consequences of applying strategy 1 is requested.
C_{10}: The required information is provided in tabular form and both for the case when the strategy 1 is used and for the reference case. A broad set of indicators is used at this stage which contain important economic factors as well as the energy variables. This is the final stage in the decision making process and a final, broad look at the consequences of using the selected corrective measure must be taken.
I_{11}: The performance of the economy and the energy sector is assessed as satisfactory (recognising the constraints imposed) and the final decision for implementation is made.
C_{11}: The causal stratum model advances to the next year—1971.
I_{12}: Information on the basic indicators is requested in tabular form, in reference to the anticipated problem area which, again, is the increase in the cost of production.
C_{12}: Information is provided both for the reference case and the problem case.
I_{13}: Information on the policy set requested.
C_{13}: Policy set provided.
I_{14}: The interactor is familiar with the policies (having already experience in this problem area) and proceeds immediately to select the policy.
C_{14}: It is indicated that no additional investment is needed for policy 1.
I_{15}: Information on the consequences of actually applying policy 1 is requested in tabular form.
C_{15}: Requested information provided in the standard format.
I_{16}: Decision to apply policy 1 for a three year period is made.
C_{16}: Policy 1 is applied for the indicated 3 year period (1971–1974) and the causal stratum model advances for 3 years. Information on the actual performance of the economy and energy sector is presented in tabular form *(not all shown here)*.
I_{17}: The interactor is experienced in the given problem area and immediately proceeds to adopt policy 4, strategy 3.
C_{17}: For the implementation of the strategy, the interactor is requested to specify the investment level; some links to that effect are provided.
I_{18}: Interactor decides on the investment level.
C_{18}: Interactor is requested to decide on the investment mix as well as on the increase of the cost to the consumer (for generating larger investment fund).
I_{19}: Decision on the parameters asked for in C_{18} is made.
C_{19}: The level of total investment in actual terms is again indicated.
I_{20}: The interactor decides to apply the selected policy for a 6 year period.
C_{20}: Decision from I_{20} executed and the model advances for a 6 year period, ie, up to 1980. The historical information on the performance of both the economy and energy sector over the entire 10 year period is given *(not all shown here)*.

to investigate the effect of any given policy applied consistently over a period of time or of a switch from one policy to another. Even in the present system which is but one element of the system yet to be developed, the number of realistic situations which can be considered by the model is very large.

Appendix

The energy-economic model on the causal stratum

In this section we shall describe the basic structure of the causal stratum model.[2]

At the heart of the model are the long-term economic growth and development relationships. They include the following:

The production balance equation: $X^t = A\,X^t + Z^t + I_0^t$

where X^t is the vector of gross sectorial outputs, Z^t is the vector of total consumption (including export-import), while I_0 is the investment by origin, ie, the production of capital goods. All vectors are given at time t as indicated by superscript. The total consumption vector is further decomposed into various more specific components including exports and imports.

The production function: $V^t = f_v(K^t, L^t)$

where V^t is the vector of values added, K^t the capital and L^t the labour by sectors. Various forms for f_v have been used in different generations of the model.

The capital formation: $K^{t+1} = K^t + I_d^t - D^t K^t$

where I_d^t is the investment by destination vector while D^t is the capital depreciation matrix.

The behavioural relationship for public consumption: eg $C^t = f_c(C^{t-1}, y^t)$

where C^t is the public consumption while $y^t = \Sigma\, Y_j^t$ is the total gross regional product, or income; similar relationships are introduced for government consumption, for imports, etc.

The energy demand relationships which are derived either on the basis of the *gross regional product per capita*, by taking into account the structure of the economy, or, more directly in terms of the *energy per capita*. These are presently based on the projection of past trends.

The energy supply relationships which are derived starting from the *energy sector output* as given within the economic model in reference to the type of energy production technology.

The model has been constructed on the basis of data for a 20 to 50 year period, depending upon their availability. The world economic system is divided into ten interacting regions on the basis of the stage of economic development and the socio-political arrangements which affect the economic development. The regions are: Western Europe, North America, Japan, and the Rest of the Developed Market Economies; Centrally Planned Economy (Europe); Oil Producing Countries; Rest of Africa; Centrally Planned Economy (Asia); Rest of Asia; and Latin America.

References

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VI.4. CONVERSATIONAL USE OF MULTI-LAYER DECISION MODELS

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In order to avoid the pitfalls of relying solely on the computer for policy analysis which by necessity leads to a mechanistic view of the situation, one can use what is called a multi-layer decision model in which man and computer work as partners in analysing the decision situation. Each assumes the role assigned so as to use the capabilities of both to the best advantage.

In such an operation the analysis is the outcome of both the logical and computing capabilities of the machine on the one hand and the intuition, experience and heuristic capability of man on the other. This approach is fully consistent with the major aim of the M-P world model which asks for the representation of decision-making and goal-seeking processes: a practical way to implement such a model is by a conversational mode of operation. This permits evaluation and assessment of intangibles such as technical innovation, discoveries, new and unexpected substitution possibilities, the effect of reduced diversity in the cultural ecosystem and above all the social, political and psychological developments.

The computer contains a representation of dynamic processes relevant for the situation (problem) of concern, the alternatives available to the decision maker for affecting the situation and the constraints which he must observe in implementation. The decision maker observes changes during the evolution of the system in time (via an appropriate set of indicators) and by using his judgement determines when a corrective action is called for. Depending upon the specific aspects of the undesirable behaviour, the decision maker asks the computer for more detailed information on the situation, the type of goals, policy alternatives, actions and measures available, the constraints to be observed, etc. He then makes appropriate decisions and instructs the computer accordingly. As a rule, the interaction between the decision maker and the computer is more complicated, involving numerous iterations before a final set of decision is made. However, the basic division of labour between man and machine is always the same: man decides on values, priorities, costs and the level of risks to be taken; the computer indicates the breadth of choices and likely consequences.

The oil shortage crisis has been selected here as an example of implementation of a decision model because of the paramount importance which energy plays in all aspects of the world system. In this paper, we describe the use of the model for the decision analysis of the oil shortage crisis in North America (Region 1). Of course, when the model is fully developped, each region can contain a representation of its own decision process.

The decision process represented in this model occurs under the condition of a crisis situation.
A distinctive feature of a crisis situation is its time period: short-term, usually in the 1 to 3 years range; intermediate, 3 to 10 years; and long-term, over 10 years. We shall consider the case of a medium-term crisis here. Although our concern in principle is with long-term development, the events surrounding an intermediate crisis are much easier to describe in familiar terms and on the basis of more reliable data. The conversational mode analysis can therefore be more easily assessed.

Basic Structure of the multi-layer decision model

The basic physical components are the interactor and the computer (Figure 1). The computer contains a programme which has two levels or strata: the decision stratum and the causal stratum (Figure 2).

The decision stratum models various functions performed in the process of arriving at a decision and the conditions and constraints under which the decisions are made. The interactor together with the decision stratum programme represent the decision-making part of the system.

The causal stratum represents the model of the regional economy and the basic energy relationships. The model reproduces the evolution of the basic economic processes and functions of the economy over time: production, consumption (government and public), export-import, capital formation etc. The energy relationships give the supply and demand of energy as well as inter-regional imports and exports. The behaviour and performance of the economy is described in terms of a large set of appropriate economic indicators. The causal stratum also contains a model of population growth designed only to indicate the level of population at any particular time and as needed in the decision process, rather than giving a more detailed demographic description of the region.

The decision stratum contains four levels, termed decision layers or simply layers, as indicated in Figure 3 - the goal layer, the policy layer, the action layer and the implementation layer. Each of the layers is assigned a specific role, and their functions are broader and concerned with longer time periods. The lower layers' functions are more technical and concerned with more immediate objectives. The final decision is the result of a coordinated response of all layers. The policy layer is responsible for the broad decisions formulated in reference to political and social expectations and possibilities. For instance, in the case of the independence goal, one wants to achieve this goal but at the same time limit the economic impact during the phase of transition.

The action layer is responsible for finding the actions to carry on the selected policy. For example, if the overal policy is generally to limit the economic impact, one action would be to shift investment from other sectors (services or agriculture) to the energy sector, while another can be to select a minimum output growth rate.

Finally, the implementation layer is responsible for determining the exact magnitudes of changes needed for implementation. For example, if the strategy is to shift 40% and 60% of the investment from the industrial and service sector respectively, then the implementation layer determines the exact value of investment needed, its effect on other investments, on imports et To illustrate the process of using the system as a decision-making tool, the time sequence of a typical man-machine interacti is given in Figure 4.

Rules for the Conversational Mode Operation

- Conversational rules

The interactor communicates with the machine by means of an elementary command language. Such a language is designed so as to be simple for inputing while at the same time containing sufficient elements to convey the meaning to the interactor at least in one of the natural languages. We present in table 1 the simplest possible version of such a language which, however, is sufficient for the analysis of some important long-term policy decisions.

The interactor should use words which are both properly constructed and are appropriate to the stage of the decision process. One type of mistake he can make is to use a word which is not in the dictionary. He might also use inappropriate words. For example, he might use a word which denotes the selection of a specific action before the general goal and policy have even been selected. If the interactor makes a mistake by communicating a word which is illegal by construction or at the stage of the decision process, the computer instructs the interactor about the mistake and indicates the type of mistake made.

The interactor has two basic classes of inputs: requesting and instructing. The request inputs are of different kinds depending on both the stage in the decision process and the format in which the information is to be presented. They also might refer to the set of policy alternatives or actions available. The instruct inputs are primarily decisions on policies, actions, parameters, on implementation or on return to a previous stage for additional considerations.

The computer responds by statements in English with desired data or graphs. A special effort is made to present the computer outputs in the most usable form; indeed no special instruction is necessary to read and understand the printouts, the only requirement being to understand the problems and issues involved and the indicators and variables of importance. The interactor follows a conversation like the one shown in Figure 4. He can construct his own sequence which of course must be internally consistent.

An Example of the Conversational Policy Analysis

In order to illustrate the possibilities provided by the multilayer model a complete printout of the policy analysis and decision process spanning over a 5-year period is given in Figure 5. To facilitate understanding of the structure of the printout, each inputing time is indicated by an arrow (I_1, I_2, etc).

This example of the conversational mode is far from indicating all the flexibility of the approach. However, it does illustrate what kind of process and interaction is involved, helping in this way to clarify sharp distinction between this type of approach and the classical deterministic computer simulation methods. Also the format of the interaction can be designed to suit the desires of the interactor, e.g. it might be preferable to have the information presented in a graph form rather than as tables.

The system as developed so far can be used in a number of actual decision-making situations or for demonstration purposes. For example, it is possible to investigate the effect of any given policy applied consistently over a period of time or of a switch from one policy to another. Even in the present system which is but one element of the system yet to be developed, the number of realistic situations which can be considered by the model is very large.

Table 1

The Command Language

Requests

-- for information about the available alternatives

[OPT: name of layer]

-- for information about the evolution of the model

[DA]

which can be followed by

[NØR, PER+DEC, PER, ACT]

if information is needed about the normal, perceived (with or without decision implemented) or actual situation.

if one asks for energy indicators,

must be typed in [ENE]

for economic ones. [ECØ]

The outputs can be numeric (default option) or graphic

[GPH]

-- for information about the available commands

[HELP]

Instructions

-- choice of alternatives

[DEC: name of goal, policy etc. selected]

-- for running the model [RUN]

-- for restarting at initial year [TØP]

-- for stopping [BYE]

Figure 5

Computer Printout from demonstration of multi-layer decision model applied to energy problems in North America

In order to illustrate the possibilities provided by the multi-layer decision model, a complete printout of the policy analysis and decision process is given. To facilitate understanding of the structure of the printout, the interactor input is printed on the left (in lower case letters) while the computer's response is in upper case.

C_0: the analysis starts at the year 1975

I_1: the interactor requests information about the evolution of the model in the causal level

C_1: the computer answers by means of numeric outputs for energy indicators over a 10-year period

I_2: additional information is requested concerning economic indicators.

C_2: information is provided by the computer

I_3: having necessary information as to the possible cause of event in the future, the interactor requests the set of goals available for the type of problems anticipated (i.e. oil shortage)

C_3: the set of goals is provided

I_4: in the judgement of the interactor the goal IND (independence) appears to have promise and he selects it

C_4: the decision process is advanced by one step.
This decision process i.e.
- request about the available alternatives
- decision: selection of one of these alternatives
- progression to the next layer

is repeated for the policy and action layers (I_5, C_5, I_6, I_7, C_7, I_8, C_8)

I_9: on the implementation layer the interactor asks for the available selections

C_9: the information is provided

I_{10}: the decision is taken to limit the impact on economy

Figure 5 (2)

C_{10}: the interactor is requested to decide on the limit value

I_{11}: the interactor provides the limit value and decides to fix a number of years of application

I_{12}: the interactor decides to run the model over a 3-year peri

C_{12}: the causal stratum model is advanced to year 1978

I_{13}: information about the results of decision implementation i requested

C_{13}: and provided by the computer

I_{14}: before taking a decision for another period, the interacto asks about the normal evolution of the model for the nex 10 years

C_{14}: the computer replies by means of numeric outputs

I_{15}: the interactor decides to apply the SIT implementation alternative

C_{15}, I_{16}: he is requested to decide on the % value of investment transfer from other sectors

I_{17}, C_{16}, I_{18}: the interactor applies the decision for 2 years

I_{19}: he asks about the perceived evolution of the model, the decision taken above being implemented

C_{17}: the evolution of the energy indicators is given

I_{20}: the order is given to run the model

C_{18}: the model is now at year 1980

I_{21}: the results of the implementation (actual situation) are requested

C_{19}: and provided

I_{22}: a return is made to the initial year

C_{20}: i.e. 1975

I_{23}: the IMP goal is selected

I_{24}, C_{21}, I_{25}

C_{22}: the number of years is fixed by the interactor and the mod is set up to 1979

Figure 5 (3)

I_{26}: actual situation is requested

C_{23}: and provided

I_{27}: end of session

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MULTI-LAYER DECISION MODEL
-OIL SHORTAGE-
-NORTH AMERICA-

THIS IS YEAR 1975

da

nor

ene

DEVELOPMENT ANALYSIS:
-NORMAL SITUATION
-ENERGY INDICATORS

	EC	OC	OCM	FOCM	ECPC
1975	3042.343	1612.442	161.266	0.100	12.721
1976	3150.998	1701.530	183.796	0.108	13.032
1977	3263.534	1794.963	208.213	0.116	13.351
1978	3380.088	1892.869	234.713	0.124	13.677
1979	3500.896	1995.450	263.400	0.132	14.011
1980	3625.754	2102.384	294.417	0.140	14.354
1981	3755.327	2215.045	327.915	0.148	14.705
1982	3889.445	2333.557	364.052	0.156	15.064
1983	4028.354	2457.012	399.399	0.164	15.433
1984	4172.210	2585.953	437.749	0.172	15.810
1985	4321.223	2635.940	474.479	0.180	16.196

eco

-ECONOMIC INDICATORS

	Y	YPC	DY	DIE	DYE	EDIE
1975	1080.552	4.543	0.035	0.0	0.0	0.0
1976	1125.357	4.654	0.035	0.0	0.0	0.0
1977	1165.548	4.768	0.036	0.0	0.0	0.0
1978	1207.175	4.885	0.036	0.0	0.0	0.0
1979	1250.288	5.004	0.036	0.0	0.0	0.0
1980	1294.961	5.126	0.036	0.0	0.0	0.0
1981	1341.180	5.252	0.036	0.0	0.0	0.0
1982	1389.028	5.380	0.036	0.0	0.0	0.0
1983	1438.098	5.512	0.036	0.0	0.0	0.0
1984	1489.080	5.646	0.036	0.0	0.0	0.0
1985	1543.295	5.784	0.036	0.0	0.0	0.0

opt:goal

ALTERNATIVE GOALS:

1.USERS TECHNOLOGY ADAPTATION UTA
2.INDEPENDENCE IND
3.DEPENDENCE ON IMPORTS IMP
4.INTERNATIONAL COOPERATION COP

```
I6  [ dec:ind
            -POLICY LAYER:                                           ] C4
I5  [ opt:pol
                  POLICY OPTIONS-IND GOAL:                           ]
                                                                     ]
               1.MINIMAL TRANSITION TIME            MTT              ]
               2.LIMIT ON ECONOMIC IMPACT           LEI              ]
               3.CONSERVATION DURING TRANSITION     CDT              ] C5
               4.IMPORT DURING TRANSITION           IDT              ]
               5.MIXED POLICY                       MP               ]
            -POLICY LAYER:                                           ]
I6  [ dec:lei
            -ACTION LAYER:                                           ] C6
I7  [ opt:act
                  IMPLEMENTATION MEASURES-IND GOAL-LEI POL:          ]
                                                                     ]
               1.INCREASE OF TOTAL INVESTMENT                 ITS    ]
               2.TRANSFER OF INVESTMENT FROM OTHER SECTORS    TIOS   ] C7
               3.REDUCTION OF CONSUMPTION                     RC     ]
               4.MIXED STRATEGY                               MS     ]
                                                                     ]
            -ACTION LAYER:                                           ]
I8  [ dec:tios
            -IMPLEMENTATION LAYER:                                   ] C8
I9  [ opt:imp
                  IMPLEMENTATION SELECTIONS-IND GOAL-LEI POL-TIOS MES:  ]
                                                                        ]
               1.LIMIT ON ECONOMIC IMPACT         LIM                   ]
               2.SOURCES OF INVESTMENT TRANSFER   SIT                   ] C9
               3.NUMBER OF YEARS OF APPLICATION   NYA                   ]
                                                                        ]
            -IMPLEMENTATION LAYER:                                      ]
I10 [ dec:lim
        FIX LIMIT ON ECONOMIC IMPACT:                                   ] C10
I11 [ 1
    [ dec:nya
        HOW MANY YEARS DO YOU LIMIT THE MODEL TO RUN ?                  ] C11
I12 [ 3
    [ run
               THIS IS YEAR 1978                                        ] C12
```

I_{13}

da

act

ene

DEVELOPMENT ANALYSIS:
-ACTUAL SITUATION
-ENERGY INDICATORS

	EC	OC	OCM	EOCM	ECPC
1975	2798.056	1483.446	161.244	0.109	11.703
1976	2819.541	1522.552	179.358	0.118	11.661
1977	2837.223	1560.472	198.133	0.127	11.607
1978	2851.922	1597.076	217.528	0.136	11.540
1979	2863.567	1632.233	237.494	0.146	11.461
1980	2872.099	1665.817	257.980	0.155	11.379
1981	2877.404	1697.704	278.930	0.164	11.267
1982	2879.021	1727.772	300.281	0.174	11.153
1983	3218.400	1727.122	316.690	0.183	12.339
1984	3333.342	1812.111	349.734	0.193	12.631
1985	3452.390	1870.091	379.072	0.203	12.940

I_{14}

da

nor

ene

DEVELOPMENT ANALYSIS:
-NORMAL SITUATION
-ENERGY INDICATORS

	EC	OC	OCM	EOCM	ECPC
1978	2851.922	1597.076	217.528	0.136	11.540
1979	2867.355	1634.392	237.494	0.145	11.479
1980	2880.902	1670.925	258.086	0.154	11.405
1981	2892.525	1706.590	279.274	0.164	11.326
1982	2902.199	1741.314	301.025	0.173	11.241
1983	3231.751	1745.921	318.904	0.182	12.391
1984	3347.171	1834.330	351.185	0.191	12.683
1985	3466.712	1895.612	380.645	0.201	12.994
1986	3590.523	1991.065	418.511	0.210	13.311
1987	3718.750	2057.543	451.093	0.220	13.637
1988	3851.568	2126.250	487.140	0.229	13.970

I_{15} dec:slt

I_{16}

CHANGE % OF INVESTMENT SHIFT FROM AGRICULTURE FROM 0 TO:

10

CHANGE % OF INVESTMENT SHIFT FROM INDUSTRY FROM 100 TO:

80

CHANGE % OF INVESTMENT SHIFT FROM SERVICES FROM 0 TO:

10

[I17] dec:nya

HOW MANY YEARS DO YOU WANT THE MODEL TO RUN ? [C16]

[I18] 2

[I19]
da
per+dec
ene

DEVELOPMENT ANALYSIS:
-PERCEIVED SITUATION
-DECISION IMPLEMENTED
-ENERGY INDICATORS

[C17]

	EC	OC	OCM	EOCM	ECPC
1978	2851.922	1597.076	217.528	0.139	11.540
1979	2935.489	1673.229	243.459	0.146	11.749
1980	3021.177	1752.282	271.371	0.155	11.950
1981	3109.029	1834.327	301.377	0.164	12.174
1982	3199.086	1910.451	333.594	0.174	12.390
1983	3689.093	1974.836	362.112	0.183	14.008
1984	3811.431	2072.016	390.805	0.193	14.443
1985	3947.553	2138.310	433.441	0.203	14.786
1986	4088.537	2242.873	476.559	0.212	15.157
1987	4234.551	2314.571	514.592	0.222	15.529
1988	4385.781	2388.531	554.713	0.232	15.908

[I20] run

THIS IS YEAR 1980 [C18]

[I21]
da
act
ene

DEVELOPMENT ANALYSIS:
-ACTUAL SITUATION
-ENERGY INDICATORS

[C19]

	EC	OC	OCM	EOCM	ECPC
1978	2851.932	1597.076	217.528	0.136	11.549
1979	2934.071	1672.933	243.459	0.146	11.747
1980	3020.993	1751.654	271.370	0.155	11.956
1981	3107.327	1833.323	301.372	0.164	12.167
1982	3196.713	1918.028	333.584	0.174	12.381
1983	3679.825	1972.975	362.094	0.184	14.027
1984	3811.247	2069.804	399.276	0.193	14.442
1985	3947.363	2135.519	433.429	0.203	14.795
1986	4088.340	2259.529	476.536	0.213	15.157
1987	4234.348	2319.659	514.552	0.223	15.527
1988	4385.579	2384.266	554.086	0.233	15.907

I_{22} top

THIS IS YEAR 1975

I_{23} dec:imp

-POLICY LAYER:

I_{24} dec:nya

HOW MANY YEARS DO YOU WANT THE MODEL TO RUN ?

I_{25} 4

run

THIS IS YEAR 1979

I_{26} da

act

ene

DEVELOPMENT ANALYSIS:
-ACTUAL SITUATION
-ENERGY INDICATORS

	FC	OC	OCM	FOCM	FCPC
1975	3042.343	1612.442	161.244	0.100	12.721
1976	3148.832	1700.372	183.940	0.108	13.023
1977	3258.709	1792.339	207.911	0.116	13.331
1978	3372.315	1888.406	234.173	0.124	13.645
1979	3490.474	1990.009	262.540	0.132	13.960
1980	3610.365	2094.011	293.101	0.140	14.293
1981	3735.075	2203.604	326.146	0.148	14.620
1982	3863.903	2319.210	361.041	0.156	14.965
1983	3996.305	2397.793	393.239	0.164	15.310
1984	4133.090	2521.195	433.644	0.172	15.660
1985	4274.055	2607.173	469.291	0.180	16.000

I_{27} bye

figure 1

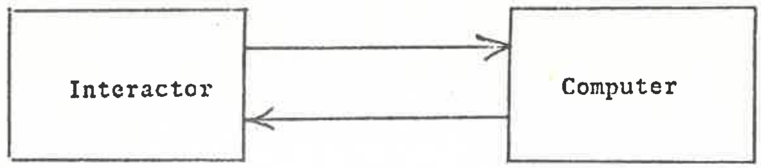


figure 2

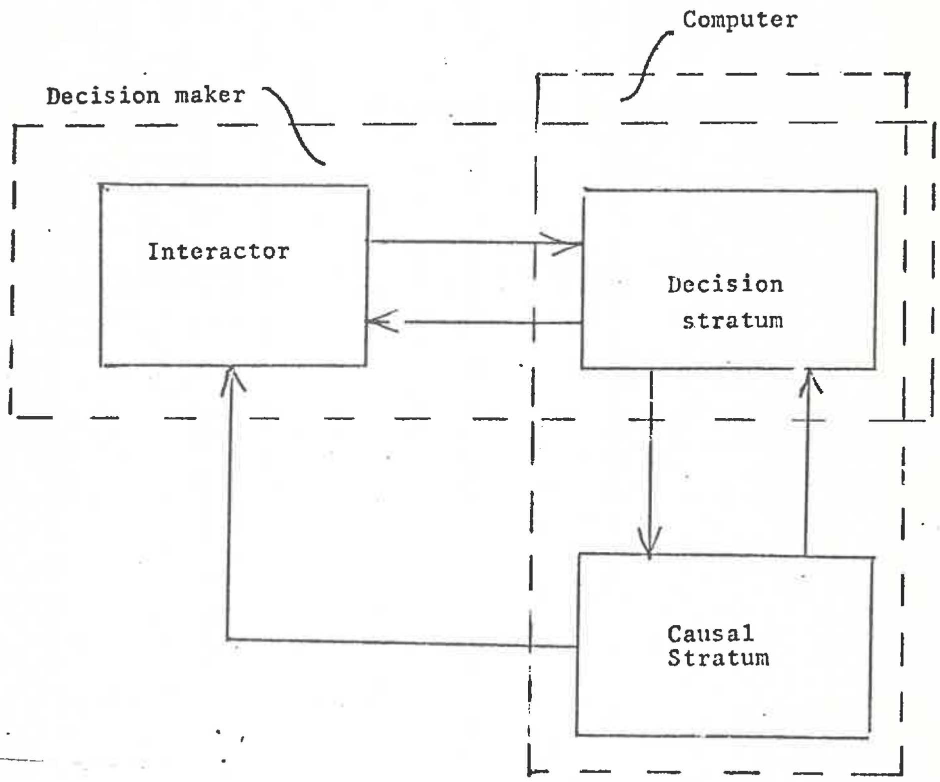
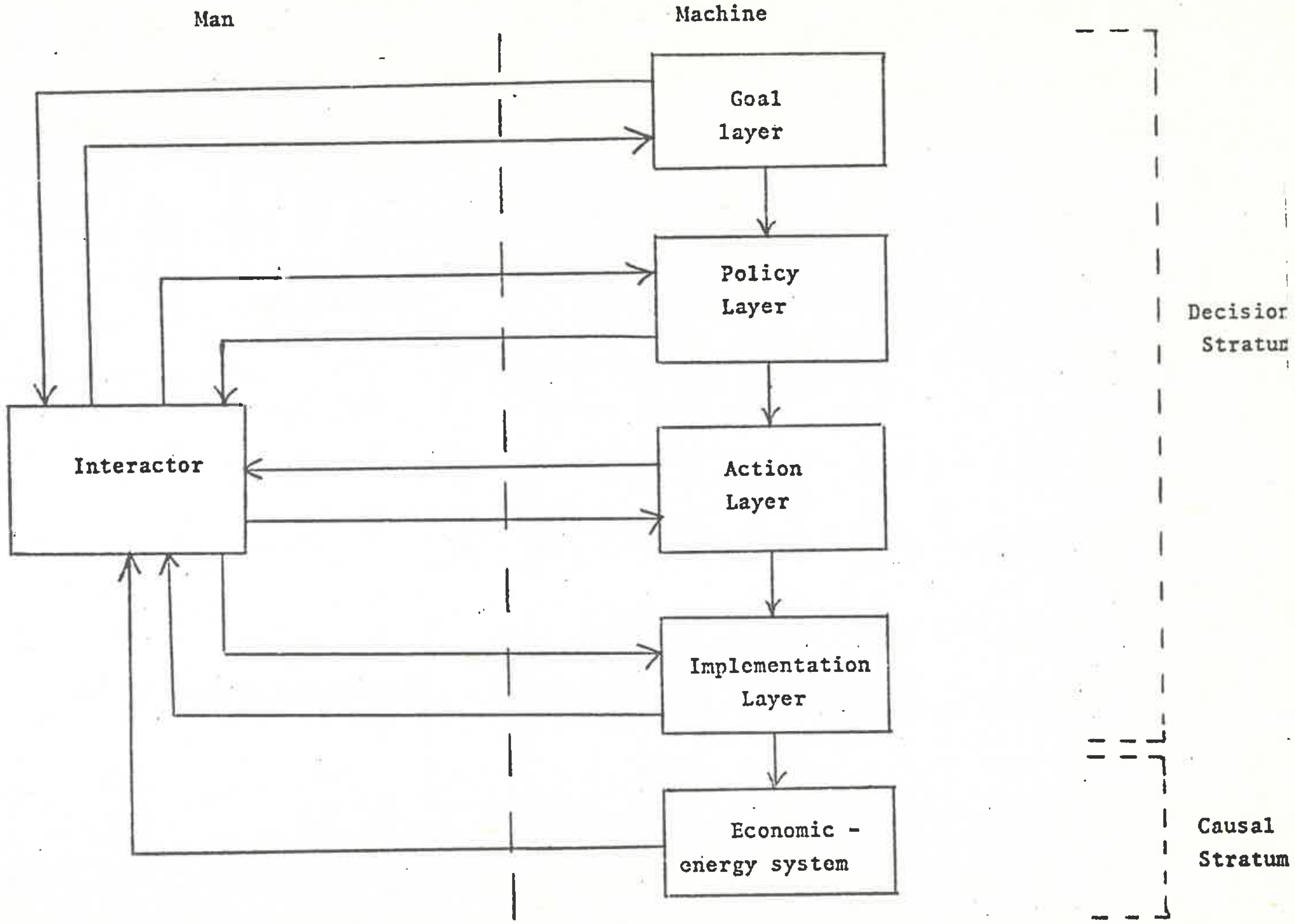


figure 3


Man
Machine
Goal layer
Policy Layer
Action Layer
Implementation Layer
Economic - energy system
Interactor
Decisior Stratur
Causal Stratum

VI.5. PROMETHEE:PROGRAMMED SUPPORT FOR MODELS OF EARTH TRENDS HIERARCHICAL ECONOMICS AND ECOLOGIC

J. Mermet

April 1974

I GLOBAL MODELLING: goal and specifications of the software tools

Two kinds of problems are raised by the modelisation of large systems. Firstly those relative to the construction, descriptio of the model and setting up; secondly those linked with its operation, use and the interpretation of the behaviour of these models.

The first category of problems is tied up with a good knowledge of the system described:

"Ce qui se conçoit bien, s'énonce clairement",

Thus a well-known system (economic, ecologic) may have a good computer representation. On the other hand even if one elaborat on the most sophisticated software tools, it would be an illusion to hope for significant results of the described models, if there were only a rough knowledge of the functioning laws of the simulated phenomena or if there were no coherent and complete dat with which to provide the model in operation. No mathematical formalism, no language may perform the miracle of compensating fo a user's lack of knowledge.

The computer tool may be more or less powerful as regards to the means of calculation, more or less precise and practical with regards to the expression of the reality but it adds nothing to th validity of the interpretation of the results provided. This validity remains the sole responsibility of the person using the software tool to construct his model. This basic fact might wel be remembered since nowadays any model having been operated on by a computer is considered "sacred" and provokes passionate judgeme of the results provided, however poor they may be.

Useful model construction necessitates three things: an ever-improving knowledge of the described "reality", an intuition of its functioning law , a vast experimentation. It is here that t computer tool may considerably accelerate progress. The experimentation of the model of "complex systems" may never be similar to that of physicists who try to reproduce the real phenomenon in observable conditions. The system studied is too complex to be reproduced, sometimes it may only be described in a formal language. This description may be treated by a computer in course of simulation, which is supposed to represent the working of the described system. Whoever has carried out the description is going to observe the simulated working, if he is n satisfied he will be lead to guess certain modifications of the model and to translate them in his description before simulating a new operation. It is only after a long experimentation on a model and innumerable attempts, that progression towards a closer approximation to the reality may be hoped for. The description language of the model must therefore be concise and simple to use (thus with a high-level syntax), must possess as basic ideas the principal concepts existing in the described systems, must possess an associated set of programmes in order to verify the syntactical correction and the internal coherence of every description and must automatically translate this description into a programme which may be used directly for a simulation.

The first category of problems raised by the modelisation of complex systems is thus defined by a "Model Description Language" (one or several) and needs a system of programmes to perfect this description and to compile it into a model ready to operate on.

This module and many others already perfected must now be assembled and interconnected in order to form an arbitrarily complex system of interacting programmes, simulating a set of interactive processes This leads us to the second category of problems raised by the modelisation of complex systems - i.e. the setting up of the models their use and observing the course of operation.

Firstly the user of the described models,with the help of the languages previously called to mind, (not forcedly the one who made the models) should be able to command the setting up of these models according to different scen--arios which he wants to test. Thus he must have at hand a command language and a scenario description language (which may be an extention of the command language). In order to use the models which he can command, he must define with the aid of the scenario description the initial data, and the parametre values which constitute the context of the simulation. Likewise, in a given time he must provide the new values of the parametres which change in course of time. All these data come from an immense "data base" with easy access.

Finally the user must be able to intervene at any stage in the evolution of the model, either to observe the state of the system or to modify its subsequent evolution. The model itself may be conceived in such a way as to stop periodically in order to ask the user for the data essential for the continuation of the evolution. (e.g. political choice) All these input-output commands, loadings or readings will be managed by an interactive system promoting dialogue between man and machine.

However, one can go further and desire to allow the possibility of a dialogue between the models and several users at one and the same time, each taking decisions independently when at the command of one part of the model. Eventually it may be presumed that each user has access only to one part of the system and not to certain sub-models which may belong personally to other users and be considered as confidential. Thus the problem is raised concerning the protection of private files and the interaction of sub-models or black boxes which must nevertheless converse together. The whole programmed support of a system for the modelisation of complex systems thus includes a formalism of "Model description" (one or several languages) and the associatedverification and compiling programmes, a system of "Management of data base", a "Command language" (and one of scenario description) and an "Interactive system." This interactive system is capable of interpreting the "Language of commands and scenarios", of assembling modules compiled from the "Model description language", of reading or writing data which is regrouped in the input (or output) file close to the "general data base" and of allowing the dialogue between the model and several simultaneous users. Before describing briefly the principal constituents of PROMETHEE, we shall examine some propertie of the systems to be modelled.

2 Structure of the Systems

It would be absurd to claim to describe a complex system by a monolithic model, even if it is formed from a very great number of variables and equations. A reasonable approach consists in subdividing the system and then arranging these subsystems in groups etc. e.g. world, then 11 regions, then cutting these up into several subregions and eventually countries . . . Similarly if a schema of a complex decision is to be modelled for example, the problem would be decomposed into sub-problems and thus the objective would be composed from sub-objectives. Finally it is surely sensible to form several separate models from one and the same system, each one reflecting a formalised yet incomplete view of the system. (e.g. industrial production for one region, water pollution for the same). Thus several models of the same entity may be obtained, each in its turn being able to be cut up in a different way into submodels. The grouping of the properties of complex systems done by Mesarovic (6) is sufficiently clear as to enable a return to them. We must, however, reproduce these concept in the "Description language" in order to be able to describe any structure in the system. Three basic notions of the description language are sufficient to reflect "stratified" or "hierarchy formed" structure to take the terminology of the Mesarovi team.

a. Definition of a Hierarchy

"A hierarchy is an oriented network without a cycle". In the field of complex systems this mathematical definition coincides with the structures encountered in two cases.

b. Precedence Hierarchy

The system described may be a set of interconnected subsystems forming a network without a cycle. It is the above-mentioned case of a tree of decisions where the leaves lead to the root, each sub-problem able to be treated only when the preceding problems in the hierarchy have been resolved. (e.g. hierarchy

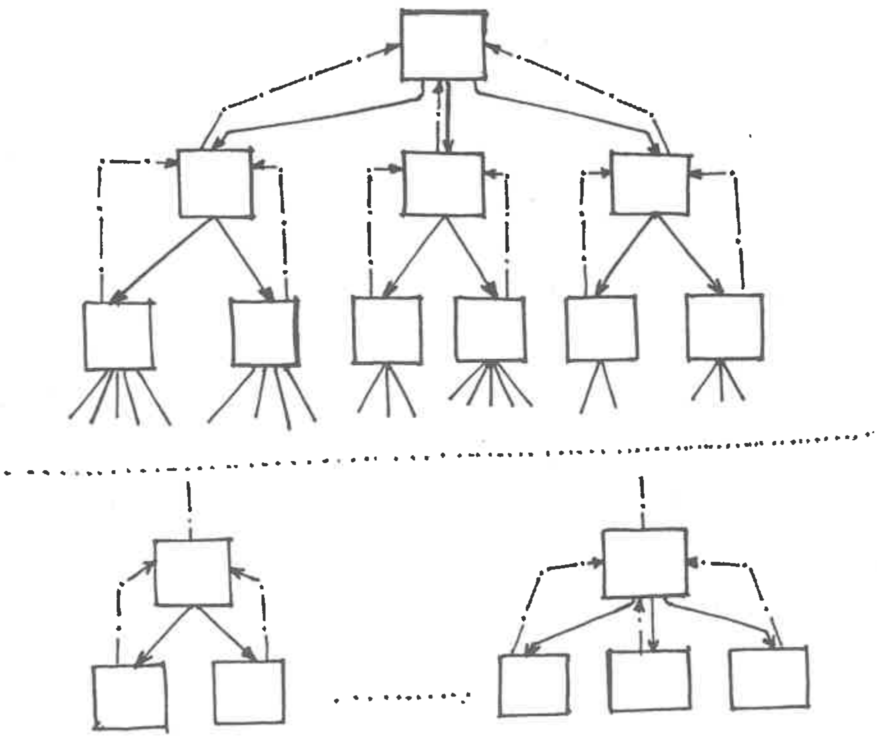


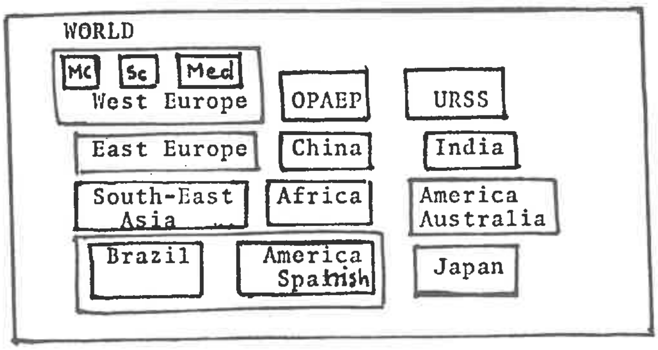
figure 1

connected by the broken lines in figure 1) In the opposite direction, any decision taken at the root may be subdivided into sub-decisions by degrees up to the leaves of the decision tree. e.g. hierarchy connected by the full lines in figure 1) A precedence hierarchy is thus termed because the direction of the arrows coincides with the chronology.

c. Inclusion Hierarchy

Each part of the described system may be divided into sub-pa e.g. the model is regionalised. This cutting up leads to a relation of order - that is to say of one system to be included in another one. This relation of order may be illustrated by a oriented tree, here termed Inclusion Hierarchy.

Figure 2



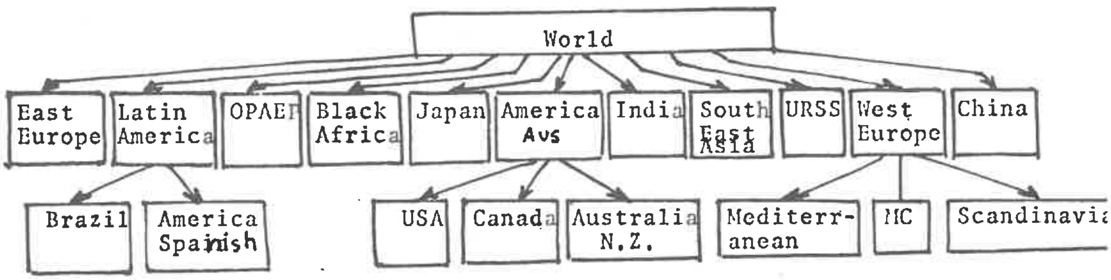
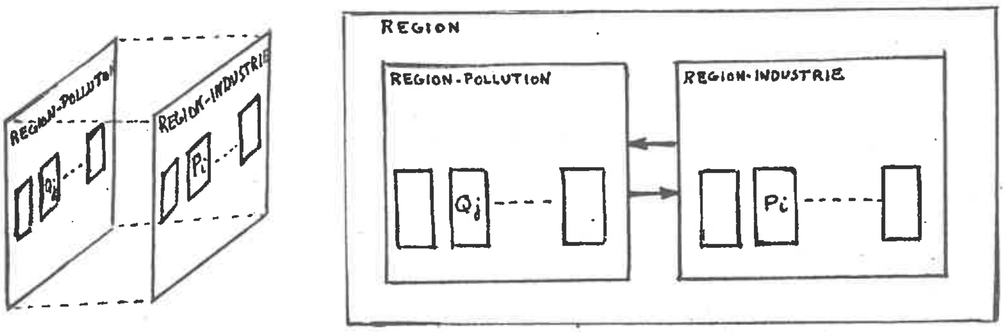


Figure 3

d. Strata

Two different descriptions of the same sub-set may each be sub-divided, thus forming 2 distinct Inclusion Hierarchies (regionalisation). Nevertheless, it is indispensable to make the sub-set interact. Each one would constitute a stratum, but the strata interactions may only be achieved between sub-sets with the same contours. In the given example, the interaction of the industrial production of P_i on the pollution of Q_j may only work through the aggregates. REGION-INDUSTRY and REGION-POLLUTION which correspond to the same subsystem REGION. This raises the very delicate problem of aggregation of variables and of sub-models together - a problem which has no universal solution.

The three notions set forth, Inclusion Hierarchy, Precedence Hierarchy and Stratum are combined and allow any structure of system to be described.



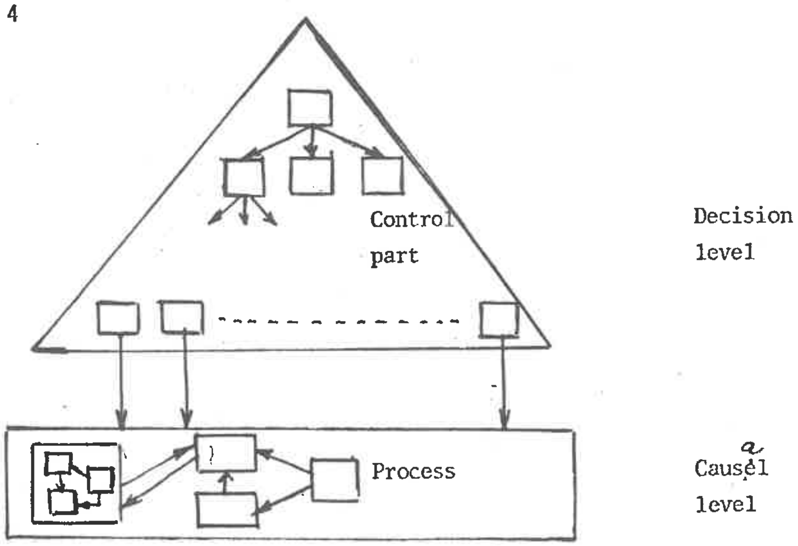
e. Simultaneity, Sequencing

Within the described process and system operation appears the notion of date. This date marks the moment when a certain number of phenomena begin to appear. The beginning of these phenomena is thus simultaneous and their processing parallel. It will be necessary to describe this parallelism of execution which does not generally exist in programming languages. A date may be absolute or relative. If it is absolute a value is given (e.g. 1974), if it is relative a mere name is given and the precedin and following dates are indicated. The set of dates necessary to describe a system constitutes on its own a precedence hierarchy.

3 LANGUAGE OF DESCRIPTION

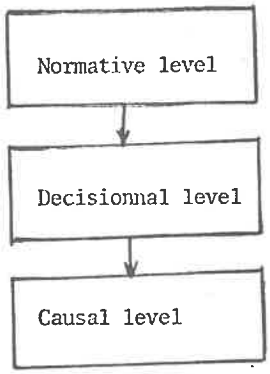
The first software tool mentioned is the language necessary to describe the systems to be simulated. The users will thus be various specialists in economy, ecology or human geography or even psycho-sociologists; if it is a question of describing the norms or the decision processes of the governmental organisations..etc

figure 4



This diversity of potential users (all those who intervene in the setting up of a global modelisation) makes doubtful the fact that one single language may be defined for all.

Mesarovic (et al) distinguishes at the <u>normative level</u> the intervention of political figures or psycho-sociologists who define the norms and political options; at the <u>decisional level</u> he notes the objectives to be attained; the strategies to reach them (which brings to mind problems of optimization) and the elaboration of the control signals of the causal level. The structural notions always find each other again and the corresponding part of the language only expresses the hierarchies and the strata. The functional notions are themselves the property of the described phenomena and may change considerably firstly between a problem of optimization under constraints or secondly production expressed by equations or even a random choice of possible decisions within a node of the decision hierarchy Up to this point our attention is held only by the causal process and with the help of economists, the functional notion presented in it have been anticipated. We reserve for the future the study of these notions at the decisional and normative level with the help of future users of the computer tool at these levels.



a. Structural notion of the language of description

These notions reflect those of the network of boxes of hierarchy and of strata which have already been used in CASSANDRE(5). They may be applied at all levels of the modelisation

a_1) Units: a sub-model describing any part of the modelised system will be called "Unit" and is located by a name and the list of its inputs-outputs e.g. Unit U.S.A. (INPUTS-OUTPUTS) - 2 units may be interconnected inside a third one which contains them.

In <u>Unit</u> U.S.A. may be found:

PENNSYLVANIA (X, Y; Z, T);
NEW YORK (Z, U; V, X);

X, Y, Z, T, U, V are the physical variables belonging to the U.S.A. the variables X (in input of PENNSYLVANIA and output of NEW YORK) and Z (the opposite) thus form an interconnection of <u>units</u> PENNSYLVANIA and NEW YORK.

a.2.) Thus every unit may contain a network of interconnected units. This structure is clearly a hierarchy of inclusion.

Preceding Example: the hierarchy represented in figures 2 and 3 may be written

<u>Unit</u> WORLD

AUSTRAMERI (in; out)
AMERILATINE (in; out)
W. EUROPE (in; out)
OPAEP (in; out)
E. EUROPE (in; out)
JAPON (in; out)
INDE (in; out)
CHINE (in; out)
URSS (in; out)
ASIE (in, out)
AFRICA (in, out)

<u>Unit</u> AMERILATINE (in; out)
BRESIL (in; out)
ESPAMERI (in; out)

<u>Unit</u> AUSTRAMERI (in; out)
AUSTRALIE (in; out)
USA (i n; out)
CANADA (in; out)

<u>Unit</u> W. EUROPE (in; out)
MEDITERRANNEE (in; out)
SCANDIN (in; out)
M.C. (in; out)

a$_3$| Strata   Let's take the example of 2 sub-models of the same set Unit PAYS-HYDRAULIQUE and Unit PAYS-ENERGIE. If there are links between the energetic and hydraulic models of PAYS which form 2 strata, they will be described in the Unit PAYS which by definition will supposedly contain these 2 and will be called unit-prefix. The units-prefix contain the interstrata links.

a$_4$| Sequences   A date will be represented as a label of a p rogramming language. Directly after the date, all the operations beginning on this date will be described. They may equally well be the calculation of a certain number of equations as the setting off of certain processes beginning at this date.

Example: 1974   A: = B+C, OBJECTIF 1(X,Y;Z), etc . . .

When the label 1974 is true i.e. when the year is in reality 1974, the result of calculation B+C is loaded into A and the setting off of the operation of the Unit OBJECTIF1 takes place, indicating that its inputs will thus be X and Y and its output Z (which will serve for example to stock the result of a calculation make in OBJECTIF1)

If the dates met are absolute when all the operations conditioned by a date have finally been validated, the position is taken up at the date immediately superior that can be found in the description. If the dates are relative, this relation is indicated by the goto orders.

Example: DEBUT, ..., goto SUITE;

After the date DEBUT, when all the operations have been considered the position is taken up at the date SUITE. Eventually there may be several orders GOTO followed by different dates. If these sequential dates have no relation, they are executed in any order. The sequence of dates of a description constitutes a precedence hierarchy. Any precedence hierarchy may thus be described reciprocally:

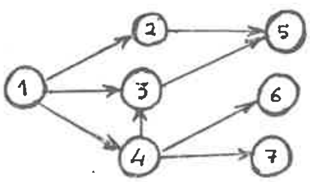
Example:

〈1〉. . . . goto 2,   goto 3,   goto 4

〈2〉. . . . .   ,   goto 5, ...

〈3〉. . . . , goto 5, ...

〈4〉. . . . , goto 3, goto 6, goto 7, ...



After 1, 2 and 4 may by executed in any order, but 4 before 3, As there is a relation between 4 and 3. Then 5, 6 and 7 may be executed in any order.

b. Functional Notions at the Causal Process Level

In order to describe the operation of the processes at the causal level, a language containing arithmetical operations is necessary +, −, *, /, Rem and the operations of relation =, ≠, >, ≥, <, ≤. The result of a relation (e.g. A=B) is a true or false boolean value, it may be used thanks to the boolean operations ∧, ∨, ¬. It might also be useful to have at one's disposal elementary functions, differentiation, sonoration, logarithm. A parallel formalism to TROLL will be adopted for this:

Example:

Usual Expression	TROLL
$\Delta K = Kt - Kt\text{-}1$	DEL(K)
$\sum_{i=-4}^{0} Kt\text{-}1$	SUM(I=-4, 0; K(I))
$\sum_{0}^{t} K$ $	TOTAL (K)

All this allows a description of the operation under form of systems of differential or differences equations. It may be useful to forecast alternatives dependent on logic conditions. For this instructions if will be used.

Example: In a model of the team Mesarovic, the equation (6) G^{+} = f1(Jt,Gt=1) is found. One might want to introduce the following alternative:
"If the total salary resulting from the market laws (supply and demand of work) becomes inferior to the total salary corresponding to the vital minimum (W^{*}) the state adds particular allocations to the salaries and this re-establishes the balance between Wi^{t} and W^{*}".

(6) becomes (6') if $Wi^{t} < W^{*}$ then $G \doteq f2(y^{t}, G^{t-1}, W^{*}-Wi^{t})$
else $G \doteq f1(y^{t}, G^{t-1})$

c. Types of Variables used

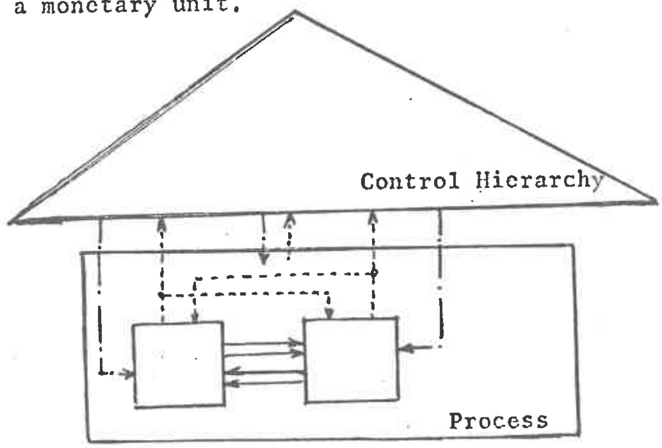
All the variables used may be a single component or vectors or matrices or . . . any type of dimension tables
e.g; A(1:8, 1:16, 1:4)

Four different types of variables are distinguished which form the subject of declarations as in the programming languages.

Level - these are physical variables
Rates - these are variables without dimensions
Function - these are calculation intermediaries
Table - their signification is clear

The type level variables may be termed money level or volume level, allowing the aggregates to be forecasted or not. The rate type variables will be instantaneous rate or variation rate. A variation rate may on principal be associated at each instantaneous rate, but it is not always known. Likewise at each volume level a money level may be associated if it is multiplied by a price given in a monetary unit.

figure5



Known specifications may be added. Monetary Unit: Franc F. which will allow an automatic conversion of the money levels. Or even production method: MPC or MPS or MPA or MPF, which will define the internal rules verified by the model in order to be coherent; according to what there is in production method, capitalist, socialist, asiatic or feudal. If certain of these rules may be formalised, a certain internal coherence of the models may be verified by programme.

These preliminary definitions allow certain rules to be laid down Every model is supposed to have the structure of figure X, where control and process are random complex characteristics.

- the contrôl contact on the process is only made by ( ) instantaneous rates.

- The process is seen from the control only by the variables of state ( )

- Only the level variables are changed between two process units, but these may observe theirrespective variables of state.

Every time rules are laid down, they may subsequently be verified by programme and the power of the computer tool placed at the disposition of the model constructors. Per contra, these model constructors must conform to a certain discipline.

d. Functional notions at the decisional level

No option has been taken in this field

- is it possible to describe notions with the help of a single language which is still to be defined?

- how may the problems of co-ordination of the different decision boxes be expressed efficiently?

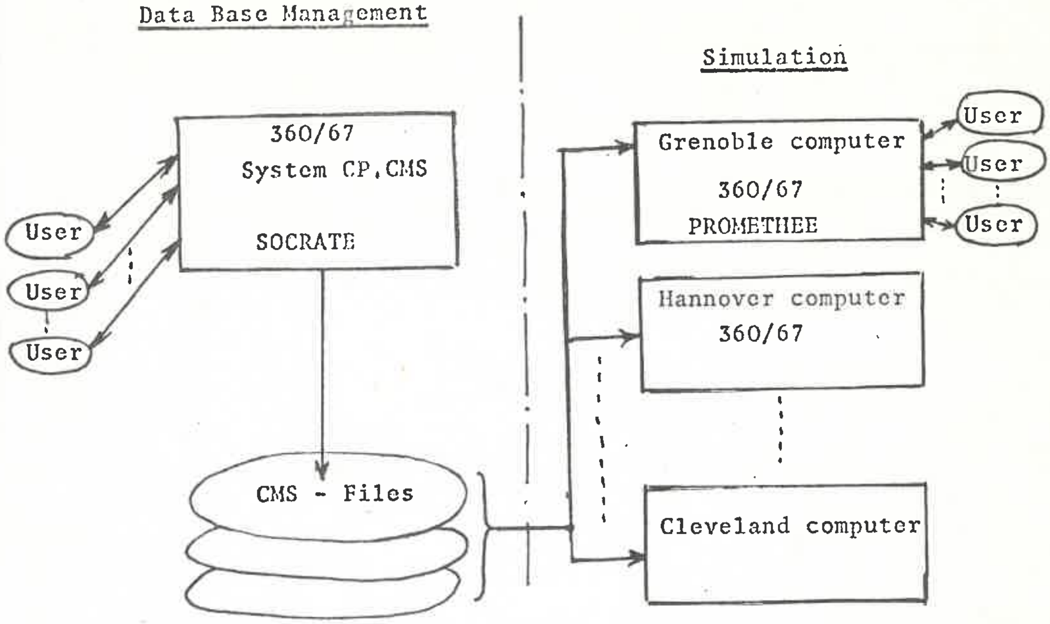
4 SOCRATE, for the Management of Data Bases

One of the most crucial problems concerning the modelisation of socio-economic systems is that of the collection and the access to data necessary for the operation of the model. One of the most precious aspects of computer science is the possibility of forming data bases, the management of which lies in the hands of the calculator. However, when numerous data bases exist in different places, a new problem arises - that of collecting them together and using them conveniently without having to restructure them totally.

This problem totally occupies numerous and important teams. Luckily for us a powerful management system of data bases, SOCRATE, has been perfected in Grenoble (1).

We are expecting to use it to exploit data bases of various origins (which could be accessible in the near future possibly through a network of interconnected computers. SOCRATE will allow the data useful for a simulation to be extracted with the least effort. We do not expect to use SOCRATE and PROMETHEE in direct interaction immediately. Later, we shall prepare files to be used for simulation with the help of SOCRATE. It should thus be possible to prepare files for machines other than our own. If more details are required on SOCRATE, reference may be made to the numerous publications on the subject.

figure 6



5 LANGUAGE OF COMMAND AND SCENARIO DESCRIPTION

What is a scenario?

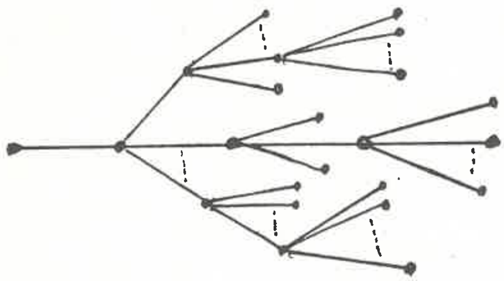
It is a period in history whose beginning is the present moment.

Thus it is a model of studied phenomena and of the environment in which it is placed. It is a set of initial conditions and constraints which are applied during its evolution. (certain constraints may be objectives) It is the duration of evolution. If no constraint is an objective, it is termed a "trend scenario".

The above is addefinition of the "elementary scenario". Once the model has been structured (causal process and hierarchy of decisions once the initial values have been allocated and the restrictions intergrated, the mechanism is triggered off for the established lenght of time. On examining the different stages an "image" of the simulated evolution is obtained.

However, one might want to introduce new data in the course of this evolution (predictions, new trends etc.). On each occasion a new context is thus loaded, the "composed scenario"is subdivided into stages.

It is therefore obvious that the definition of the new contexts of stages may in their turn be dependent on the results of the previous stage. Several scenario alternatives may be described at every stage, thus is obtained the most general case of a "composed scenario with alternatives".



Let us suppose that the model (causal process and decision hierarchy) be described in a fairly complete and flexible way so as to lend itself to all structurations resulting from the possible alternatives of a scenario and to accept all foreseeable contexts as input.

Thus a language of scenario description may be defined. This is a language allowing a tree of "composed scenarios with alternatives" to follow and allowing at every node the triggering off of a train of commands, applied to the model, containing:

- all information necessary to restructure this model and in particular its control hierarchy (of which every node may be the resolution of a sub-problem of decision)

- all the data to be injected or their address to stock the new context before setting off a new operation period.

- eventually a series of questions, conveniently sent to the users to obtain from them this structuration (choice of strategies) or these data (fixing of ceilings, etc.)

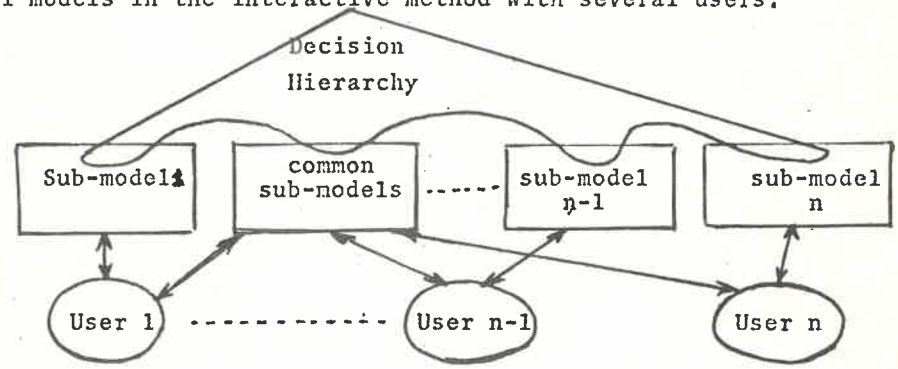
It can be seen that this scenario definition language will be very simple (if the model description language allows these models to be general enough). Studied for a very simple means of use in order to aid a non computer-scientist, this will be an extension of the command language actually constructed for the interactive system.

The user of the command language (studied by Rechenmann) and of the scenario description language is a technical specialist in neither computer-science, nor even economy ecology etc. He's a manager or a policitian. Thus the language must have a very simple syntax and be made up of very explicit orders to permit him to compose scenarios which are to be tested rapidly.

In the case of a composed scenario with alternatives, the follo-wed tree is a precedence hierarchy which may be described by known labels and goto orders indicated in 3a.

6. THE INTERACTIVE SYSTEM

For the description of this part we forward a paper by RECHENMANN. The only problem which arises is that of the operatio of models in the interactive method with several users.



Two problems are studied in particular:

a. each user has access to both a set of sub-models to which all the other users also have access and a set of models which are his own and which he must protect.

b. these protected sub-models must however communicate with the rest of the models on the one hand and the control hierarchy on the other hand. Thus we should be lead to define the extensions of the control hierarchy inside these models in order to send directives (more or less precise according to what is to found out about the model).

example: In course of operation a national and confidential sub-model may be sent the directive "Please take anti-inflationary measures". The type of measures to be taken are not known, but their effects may be judged after a certain period.

Two protected sub-models having to communicate, may only do so after their owners have established connections and exchange

-protocol (which means changing a certain amount of information on their respective models in the interactive method.

We hope to have a very limited first version of PROMETHEE before the end of 1974 and to begin to use it. Before the end of 1975 we hope to have resolved most of the problems raised during this paper, in order to be rid of them ourselves and to put at the disposition of all those who wish it, a working version of the system PROMETHEE;

I should particular like to thank Messieurs DI RUZZA, LE FAOU and RECHENMANN for their participation in writing this paper.

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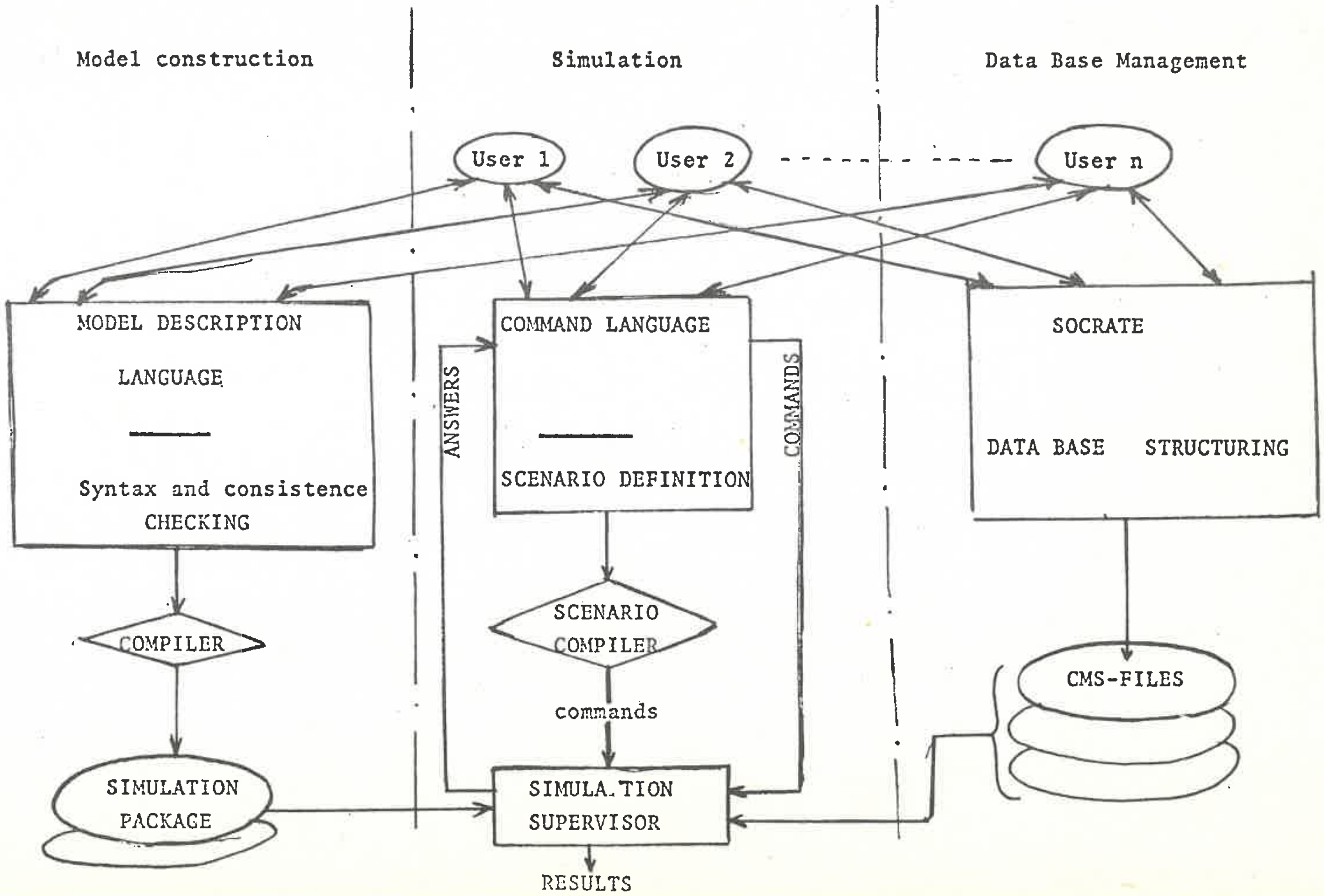
SCHEMA OF PROMETHEE



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VI.6. HUMAN COMPUTER DECISION-MAKING: NOTES CONCERNING THE INTERACTIVE MODE

J. Klabbers

April 1974

Human Computer decision-making; notes concerning the interactive mode.

1. Introduction.

Assessment of alternative developments of a social system implies that fundamental uncertainties have to be taken into account. Computer models of such systems have to be open to selection of alternatives and value judgments by the planner or decision-maker.
Systems evolution can only be estimated after specific alternatives have been chosen and the final judgment has been made.
In the context of the multilevel hierarchical approach (Mesarovic, et al , 1970) such models have been used in two ways:

- for scenario analysis
- in a human-computer simulation process i.e. interactive mode of analysis.

In this paper we will focus our attention upon the human machine configuration in which the human being provides judgment guided by norms and values and the computer program provides logical and nummerical operation.
The interactive mode is implemented as a multilayer decision system (see fig. 2).

2. Configuration of interactive mode.

Man-machine systems have been subject of extensive ergonomic research for the past thirty years, mainly under the heading of human tracking behavior.
More recently also man-computer systems have been analysed in the context of man-machine decision-making.
As we will discuss computer aided decision-making in this paper, we will look at the interface between human and computer more carefully.
The interface defines the communication pattern between human and computer, it shows the allocation of functions between both and the manner in which the task of the interactor has been structured.
Generally a human-machine system consists of two parts, the human being and the machine or process.
The state of the process is shown on an information interface, e.g. one or more displays, and the human operator changes its state, by

means of a control interface, e.g. one or more knobs of buttons, (see fig. 1).

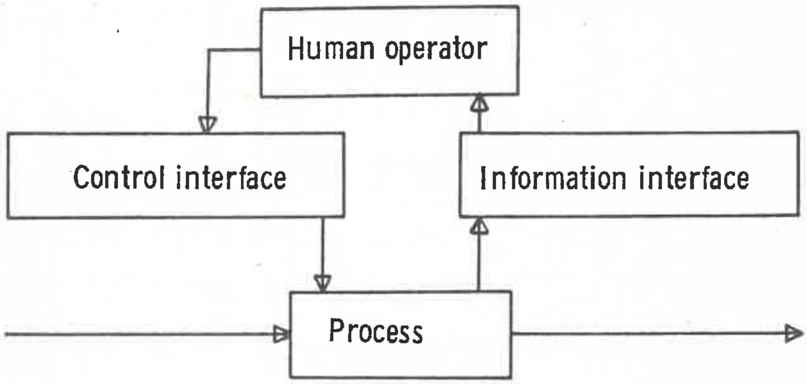

Fig. 1. Blockdiagram of a Human-machine system

A control panel in an airplane, in a space craft or in a chemical plant are examples of interfaces between human and machine.
With respect to the interactive mode the computer not only has been programmed with a causal stratum but also with a decision stratum (see fig. 2), and one can ask oneself: "How should such an interface look like in order to facilitate the actual decision-making process"?

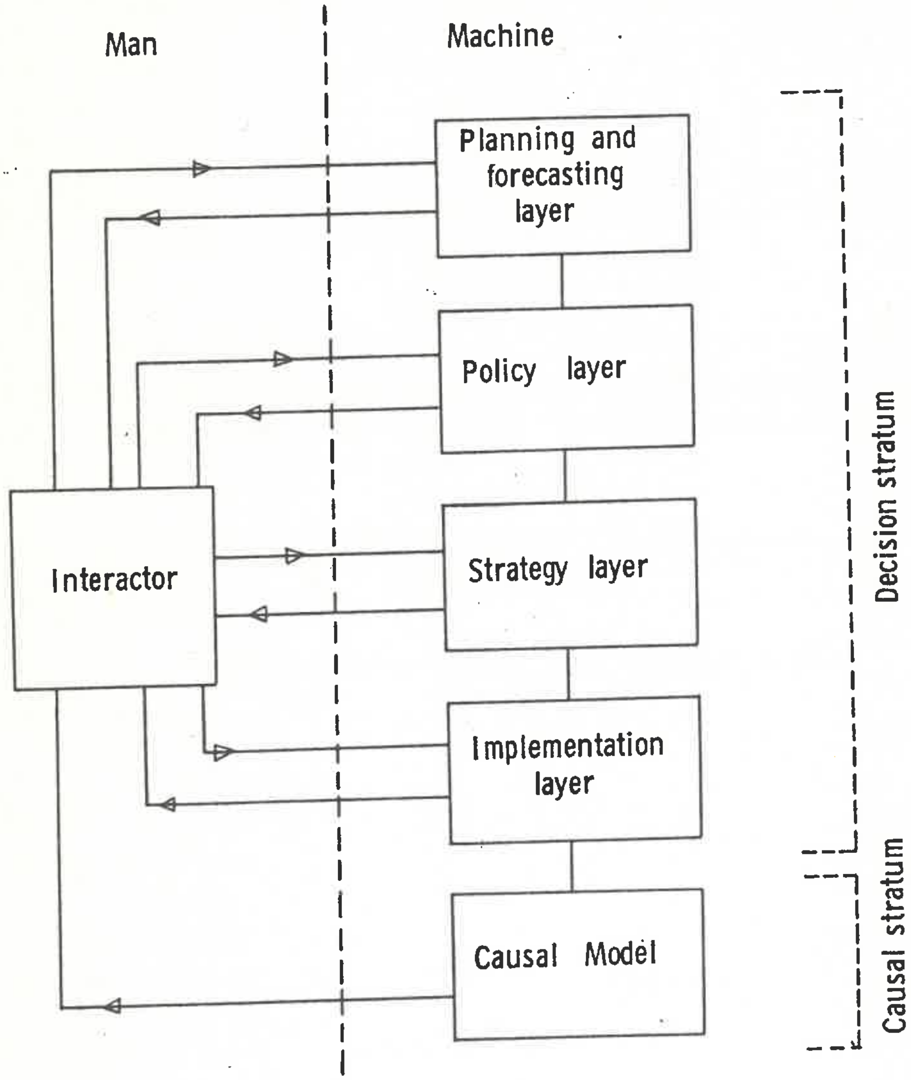

Fig. 2 Blockdiagram of interactive mode

In order to be able to evaluate human decision-making and planning properly one has to be sure that the interface as such does not interfere with the actual task i.e. planning the evolution of the system under consideration.
Therefore after a general discussion about the task of a decision maker in the context of the world modeling project (Mesarovic M.D., and Pestel E.C.), and subsequently about the related human abilities, we will first direct our attention to aspects of information retrieval.
Only after this we will discuss the way the human-computer decision can be evaluated.

3. Objectives of the human-decisionmaker, planning future developments of the system.

Using notions developed by Crossman (1960) for the task of the process operator we define the task of the interactor as follows:

1. Keep the causal stratum running as nearly as possible at a predetermined condition (stabilisation);
2. Adjust the causal stratum to give the most satisfying results according to certain criteria, e.g. yield, quality, energy consumption, income distribution etc.;
3. Make changes from one source of energy or product to another and/or change from one production capacity to another smoothly and enonomically;
4. Avoid breakdowns;
5. If such a breakdown should occur, minimize risk of damage and regain normal running as soon as possible.

To be able to control a complex social system, in the setting of the interactive simulation, the human decision-maker has to develope considerable control skill. According to Crossman (op.cit.) control skill consists of five abilities i.e.:

1. sensing - ability to detect signs and indications
2. perceiving - ability to interpret signs in relation to one another and to infer what is happening
3. familiarity with controls - knowing that means can be used to influence the process, what their effects are, and how they interact with each other.

4. anticipation - of what is likely to happen in a given situation if the system is left alone.

5. decision-making - ability to select the control action most likely to achieve the desired result in the given circumstances or to avert unfavorable developments when they threaten.

It will be clear that sensing, perceiving and familiarity with controls also depend to a large extent on the quality of the human-computer interface. These abilities play a significant part during the process of information retrieval, i.e., decision-maker-display interaction.

4. Decision-maker-display interaction.

Human decision-making belongs to the class of problem solving tasks and is almost always hierarchical: general decisions necessitate more specific decisions.
For example, a human being first decides to buy a car before he decides on which type to choose.
A decision process progresses logically from general to specific alternatives, and on many occasions decision trees have been developed to explicitely diagram available alternatives. Borko (1966), Thompson (1969), and Clauer (1972).
However, Frank (1965) and English (1965) have reported some success with a variety of textual displays and matrix formating on the CRT.
Though decision trees do not represent a universal graphical language for human-computer interaction, they have some likelihood for success in the area of relatively unstructured information searches by an investigator (Thompson, op.cit.).

In the search for a communicative human computer interface that will permit a productive and satisfying dialogue and as such influences the efficiency of hierarchical decision-making, a computer generated graphic display showing a tree structure is a good choice. Empirical evidence namely has shown that a naive searcher can learn rather quickly what options are open to him (e.g. Thompson, op. cit., Bower et al, 1969 and Clauer, op. cit.).
As an example of a tree structure we will discuss a particular computer interface developed and applied by Thompson (1971) and Clauer (1972).

for the Phosphorus Pollution Control Project (M.D. Mesarovic, et al., 1973).

Initially the display contains only the label "Index to Hierarchy" (fig. 3).

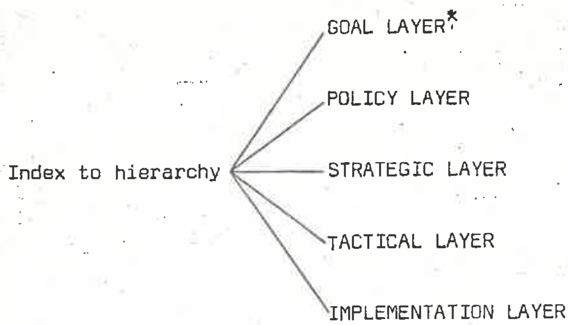

Fig. 3.: Display after response on "Index to Hierarchy".
Note: Response on "Goal Layer" results in display of fig. 4.

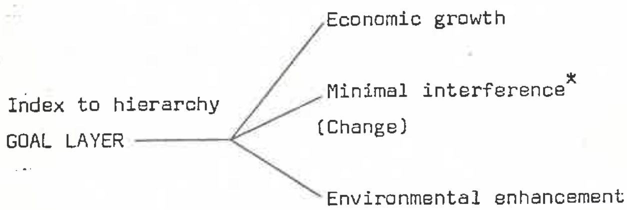

Fig. 4.: Display after response indicated on previous fig. 3.
Note: Response on "Minimal interference" results in display of fig. 5.

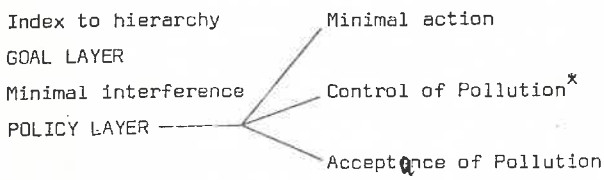

Fig. 5.: Display after response indicated on previous fig. 4.
Note: Response on "Control of Pollution" results in display of fig. 6.

Index to hierarchy
GOAL LAYER
Minimal interference
POLICY LAYER
Control of pollution
STRATEGIC LAYER

Control of phosphorus and BOD from municipal sources

Control of phosphorus and BOD from* agricultural runoff

Control of phosphorus and BOD from industrial effluents

Control of phosphorus and BOD by limiting or proscribing use

Fig. 6.: Display after response indicated on previous fig. 5.
Note: Response on "Control of phosphorus and BOD from agricultural runoff" results in display of fig. 7.

Index to hierarchy
GOAL LAYER
Minimal Interference
POLICY LAYER
Control of Pollution
STRATEGIC LAYER
Control of Phosphorus and BOD from agricultural runoff
TACTICAL LAYER

Grant supported runoff Control programs: subsidy

Fertilizer control program:* Standards

Pollution taxation-consumer

Pollution taxation producer

Fig. 7.: Display after response indicated on previous fig. 6.
Note: Response on "Fertilizer control program: standards" results in display of fig. 8.

Index to hierarchy
GOAL LAYER
Minimal interference
POLICY LAYER
Control of pollution -
STRAGEGIC LAYER
Control of phosphorus and
BOD from agricultural
runoff
TACTICAL LAYER
Fertilizer control program:
standards
IMPLEMENTATION LAYER

Reliance on u.s. standards
Additional local standards*

Fig. 8.: Display after response indicated on previous fig. 7.
Note: Response on "Additional Standards" results in display of fig. 9.

Index to hierarchy
GOAL LAYER
Minimal interference
POLICY LAYER
Control of pollution
STRATEGIC LAYER
Control of phosphorus and
BOD from agricultural
runoff
TACTICAL LAYER
Fertilizer control program:
standards
IMPLEMENTATION LAYER
Additional local standards

Return to layer
Go
Stop

Fig. 9.: Display after response indicated on previous fig. 8.

When a light pen or push button command is pointed to one of the alternatives the display shows the next node with its branches. The label chosen will be moved to the left side of the screen and its descendant labels at the next level are presented on the right side of the screen.
The search will continue till all selections at the respectively layers are made (see fig. 4, 5, 6, 7 and 8).
Before the final decision is made to run the model of the causal stratum or to return to a previous decision layer or to stop the information retrieval, on the left side of the screen the complete list of chosen alternatives at each layer is shown.

Responses which are made on the right side of the screen to proceed forward just one level are called "selections". It is however also possible to make responses on the left side of the screen, called "back-ups", and the label will be called "designated". Any previously selected mode which appears on the left side of the screen may be designated so that back-ups can occur to any prior level.
Forward selections advance only one level at a time.

Before the final decision is made to run the model one has to be sure that the interactor has developed sufficient skill in searching through the tree structure. This can be measured by the time required for each selection or designation, and by the target time i.e., the total time of all transitions having the previous target or alternative as the highest target.
For example once "Fertilizer Control Program: Standards" at the tactical layer has been selected, being the previous target, transition to the implementation layer is made automatically by the computer.

Though considerable research has to be done yet to specify typical formats for the design on practical systems for the naive user, the following implications of research can already be drawn.

-- Licklider (1967) suggests that the computer should continually inform the naive user about the options that are open to him, and that the interactive dialogue should be in the structured language (e.g. English), whenever possible.

-- Format of the tree should be such that the user search-time is a minimum.
Thompson (1968) has shown that a relative narrow tree with only four or five alternatives at any decision mode, satisfies this criterion.

-- Clauer (op. cit.) points out however that formatting variables are of small significance.
The position of targets and the span of alternatives appear to be of very little consequence on search time.
Though position, span and level have statistically positive influence on target time, their practical significance appears to be relatively small.

-- Label effectiveness in the hierarchical structures merits much evaluation especially when information communicated by such labels has considerable variability, as is the case with a fuzzy statement such as "minimal interference" at the goal layer (see fig. 4).

When finally the user-display interaction is satisfying and the interactor has sufficient skill in selecting alternatives it is reasonable to assume that conditions for sensing, perceiving and familiarity with controls are good.
Finally one can start with the actual decision making process to plan future developments of the system.

In the early stages of this process the interactor has to develop skills to anticipate systems evolution and to decide which control action most likely will achieve the desired result in the given circumstances.
Only after this learning process a plausible evaluation of interactors decision-making can be made and consequently of the evolution of the system.
During this stage of the study measurement of value change is an important indicator for assessment of social change.
What characteristics of control skill have to be taken into account during the initial stages of the decision-making process?

5. Multi-channel, multi-stage decision-making.

In the "real world" decision-making is viewed as making a number of decisions sequentially in time.
Outcomes and pay-offs of earlier decisions influence later decisions.

In this sense interactive simulation is a multi-stage or sequential decision-making process.
The planner or decision-maker observes the evolution of the system during an actual simulation run and he changes input parameters and variables in response to the systems behavior. As inputs are not fully specified for the entire period of time but in time increments, each increment is only applied after the response of the system during the previous increment has been evaluated.

The interactor indicates his decision, by selecting a number of alternatives in the already discussed decision-tree by means of a remote teletype unit and a graphic display.
The computer program computes the behavior of the system for the next time increment and prints the results on the teletype and plots the results on the graphic display for example.
The computer keeps track of both the interactor and system behavior.

Emperical results (Klabbers, 1972 and Powers, 1969) show that during the initial stages the human-decision-maker demonstrates a lack of skill in considering simultaneously all relevant aspects of the task, and that subjects focussed on only one aspect of the problem. During later stages a larger number of relevant aspects were considered when making a decision. Klabbers (op. cit.) has also shown individual differences in control strategy or control skill. To plan possible systems futures reasonably, one has to take into account individual differences between interactors, not only with respect to learning-speed but also to final control skill.

Criteria to take into account are:
- skill in handling simultaneously several factors relevant to the decision-making problem, and
- delay of reinforcement, i.e. sacrificing short-term gain for greater overall or long-term gain
- decision-making set: formulation of assumptions, norms and values which may preclude effective decision-making performance.

Certain of these factors have been highlighted by Powers (op. cit.).

Only after measuring user's skill in information retrieval and in steering systems behavior, it is possible to evaluate human decision-making in interaction with systems of regions in a reliable and valid way. Which objectives have to be taken into account we already have discussed in section 3.

6. Summary

Assessment of alternative development of a social system implies that fundamental uncertainties have to be taken into account.
This is one of the main reasons why computer models of such systems are open to human decision-making in an interactive mode of analysis i.e. human-computer decision-making.
Before future developments of the system can be estimated reliably, one first has to be sure that the human decision-maker does understand his task.
He has to develop sufficient skill in handling the available information and to understand the fundamental dynamics of the system. In this paper aspects of human control skill are discussed.
A distinction is made between information retrieval and actual decision-making to plan the system's future.
We discuss a computer generated graphic display showing a tree structure, which enables a naive searcher to learn quickly what options are open to him.
After the interactor has shown to have developed sufficient skill in handling the available information, analysis of human-computer decision-making can be started.
During the early stages of this decision-making process, i.e. a multi-channel, multi-stage control task, the interactor is not able to consider simultaneously all relevant aspects of the task.
Only after sufficient training, his control skill has been developed in such a way, that interactive simulation can be used to study systems evolution reliably.

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VI.7. THE MODELS SCENARIO ANALYSIS PACKAGE

T. Shook

April 1974

During the early stages of the development of a model, when the basic form is being defined, all the calculations are usually done manually, or with the aid of a simple calculator. The model is very loosely defined, and the calculations are done more to provide insight, and to check parameters than to produce final outputs. Efficient but rigid methods, like computer programs, would not help the model's development, so are not used. After the model has been defined, and raw data collected, programs are used to reduce the data to parameters, correct for missing data, and to aggregate the data to the correct regions and sectors or types. The computer makes it feasible to use very large amounts of raw data to produce large models. The programs used at this stage are written in FORTRAN for the development of a specific model. The data base is usually from 1o.ooo to 1oo.ooo lines.

The final stage of model development is checking the model against historical data, and doing simple projections of historical trends. The programs are still in FORTRAN, but the volume of data handled is much smaller, and the output is much more complex. More of the output is in the form of graphs, but the models are fully developed, with very few changes being made.

Once the model has been developed, it is necessary to combine it with other models and indicators to answer questions. These questions are put in the form of a scenario:a complete set of parameters over the time period of interest. The problems of programming these scenario models are more those of defining and changing the structure of the model. The input/output structure must be flexible, powerful, and easy to change: while the model remains unchanged, it is also very useful if the same model can be run on different computers with vastly different operating systems. With the addition of constraints such as costs of programming and programmer availability it became obvious that none of the currently available simulation packages was adequate. The model package that evolved to fill these requirements uses FORTRAN as the language to program the model, and a run-time interpreter to control the scenarios and do the data input/output. The package reads the dictionary for BLANK COMMON produced by the FORTRAN compiler to build its own dictionary, and will use these variables to communicate with the model. This arrangement permits all the power of FORTRAN, with vector and matrix variables, subroutines and named common blocks, while the input/output may be done much more convenientely by the interpreter. This type of package has the advantage of being very flexible with respect to its configuration on any given machine. On a smaller machine, like the GE 4o6o in Cleveland, the package can run as four overlays, and require only 8 K words of program pulse, 1 K words of COMMON and 16o K words of List. On a large machine like a UNIVAC 11o8 or IBM 36o/67 the package would all be in core at once, and would require either 35 K words of core and 11 K words of file space, or 85 K words of core. The package can be run in a minicomputer, like the PDP 11/45 with single 32 K word partition and either 18o K words or 3oo K words of disk storage. The package works with the same user interface in all environments, from batch processing to local operation with a line printer, to terminal operation with time-sharing.

Current versions of the package include the following:

FORTRAN II	assembly for the GE 4060
FORTRAN IV	for the UNIVAC 1108
FORTRAN IV	for the IBM 360/67 running CP-CMS

The FORTRAN IV versions differ in their interface with the compiler and in the way they process characters and files. The IBM version should be readily adaptable to any IBM FORTRAN with LOGICAL 1 variables. The UNIVAC version is easier to adapt when it is necessary to do the character manipulations in assembly code. The time required to install the package on a new system for someone familiar with both the package and system is about a week, with two weeks to a month being more likely if less is known about either, and if problems develop.

The manual that follows is for the GE 4060 version, with other versions of the manual under development.

THE $MODEL SCENARIO ANALYSIS PACKAGE - OVERVIEW

THE $MODEL SCENARIO ANALYSIS PACKAGE

THE $MODEL SCENARIO ANALYSIS PACKAGE CONSISTS OF 2 MAIN PROGRAMS AND 2 SUBROUTINES, THAT SIMPLIFY THE JOB OF DOING SCENARIO ANALYSES. THE ACTUAL MODEL IS WRITTEN IN FORTRAN WITH ALL OF THE DATA GOING TO AND FROM THE MODEL BEING HANDLED BY THE PACKAGE. THE TWO SUBROUTINES, COMONI AND COMONO, ARE USED TO GET AND PUT DATA FROM A DISC SCRATCH FILE. ALL VARIABLES TO BE COMMUNICATED ARE PLACED IN COMMON, AND ARE READ IN AT THE START OF EACH TIME STEP, OUTPUTS COMPUTED, AND COPIED BACK TO DISC AT THE END OF EACH TIME STEP. THE CURRENT LIMITATIONS ARE 1023 VARIABLES AND 111 TIME STEPS.

THE $DICT PROGRAM IS RUN AFTER THE MODEL, OR ANY PART OF IT, IS COMPILED, GETS THE NAMES AND LOCATIONS OF ALL MODEL VARIABLES THAT ARE IN COMMON, AND MAINTAINS A DICTIONARY OF ALL VARIABLES AND THEIR LOCATIONS. THIS DICTIONARY IS STORED IN A DATA TABLE ON DISC, AND MUST BE PROPERLY INITIALIZED. THIS DATA TABLE ALSO CONTAINS THE CONTROL PARAMETERS, THE STORED COMMANDS, AND THEIR DICTIONARY, AND THE LIST VALUES. THE CURRENT LIMITATIONS ARE 330 TOTAL SYMBOLS IN THE DICTIONARY, (INCLUDING MODEL VARIABLES, DEFINED SYMBOLS, AND COMMAND NAMES) AND 700 LINES OF STORED COMMANDS (DEPENDING ON THE SIZE OF THE DATA TABLE).

THE $MODEL PROGRAM TAKES THE MODEL, THE DICTIONARY, AND COMMANDS FROM EITHER THE CARD READER OR TYPEWRITER, TO PRODUCE

THE $MODEL SCENARIO ANALYSIS PACKAGE - OVERVIEW

PRINTED TABLES, PUNCHED CARDS, AND PLOTS FOR THE SCENARIO. $MODEL PROVIDES A CONVIENT WAY OF ENTERING OR CHANGING PARAMETERS AND TIME SERIES, RUNNING THE MODEL, AND PROVIDING ALL THE RESULTS TO EITHER CHANGE AND RERUN THE SCENARIO, OR TO MAKE RECORD COPIES FOR FUTURE REFERENCE.

THIS MANUAL IS DIVIDED INTO SIX SECTIONS. THEY ARE:

OVERVIEW - THIS SECTION

MODEL - A DESCRIPTION OF THE FORTRAN MODEL PROGRAM.

BASIC DEFINITIONS - THE RULES TO FORM VALID STATEMENTS TO $DICT AND $MODEL

$DICT COMMANDS - THE USE OF THE $DICT PROGRAM

$MODEL COMMANDS - THE USE OF THE $MODEL PROGRAM

EXAMPLE - A COMPLETE EXAMPLE OF THE PACKAGE IN OPERATION.

THE $MODEL SCENARIO ANALYSIS PACKAGE - THE MODEL PROGRAM

THE FORTRAN MODEL PROGRAM HAS THE FOLLOWING FORM:

```
          COMMON NDT
          DO 1 IY=1,NDT
          CALL COMONI(IY)
          IF (IY-1) 2,2,3
2         CONTINUE
C         PUT INITIALIZATIONS HERE
          GO TO 4
3         CONTINUE
C         PUT STATE VARIABLE OPS HERE
4         CONTINUE
C         PUT MODEL COMPUTATIONS HERE
1         CALL COMONO(IY)
          TURN PROGRAM 27 ON, 0
          STOP
          END
```

THIS PROGRAM DOES NOT CONTAIN ANY MODEL COMPUTATIONS, BUT DOES CONTAIN ALL THE STATEMENTS NECESSARY TO INTERFACE WITH THE $MODEL PACKAGE. THE FOLLOWING VARIABLES AND SUBROUTINES ARE USED:

NDT - THE NUMBER OF TIME STEPS TO RUN THE MODEL. THIS IS THE FIRST VARIABLE IN COMMON. NDT IS COMPUTED FROM FIRSTDT AND LASTDT BY $MODEL.

IY - THE LOOP INDEX TO KEEP TRACK OF WHICH TIME STEP THE MODEL IS CURRENTLY WORKING ON.

COMONI - BRINGS IN THE COPY OF COMMON, WHICH CONTAINS ALL COMMU-

NICATED VARIABLES, FROM THE STORAGE FILE ON DISC FOR THIS TIME STEP. THIS IS NECESSARY SINCE SOME PARAMETERS MAY NOT BE CONSTANT IN TIME, AND THE FILE MAY CONTAIN DATA FROM OTHER MODEL RUNS, OR FROM DIFFERENT PROGRAMS BY CHANGING PGMNUM.

COMONO - PUTS THE CURRENT COPY OF COMMON BACK ONTO THE DISC FILE. THIS DISC FILE WILL BE AVAILABLE FOR PRINTING OR PLOTTING AFTER THE MODEL IS FINISHED RUNNING.

THE COMMENT STATEMENTS SHOW WHERE TO PUT THE DIFFERENT PARTS OF THE MODEL. ANY VARIABLES THAT ARE TO BE COMMUNICATED EITHER TO OR FROM THE $MODEL PROGRAM MUST BE IN COMMON, BUT ANYTHING THAT IS TEMPORARY OR LOCAL MAY BE STORED IN THE PROGRAM. IF THE MODEL HAS ANY STATE VARIABLES, THAT IS ANY VARIABLES WHOSE VALUE DEPENDS ON THE LAST TIME STEP, THEN A SECONDARY VARIABLE THAT IS NOT IN COMMON MUST BE USED TO SAVE THE VALUE TO THE NEXT TIME STEP. THIS IS NECESSARY SINCE THE CALL ON COMONI AT THE TOP OF THE LOOP WILL BRING IN A NEW, DIFFERENT VALUE FOR EVERYTHING IN COMMON.

THE FIRST COMMENT MARKS WHERE COMPUTATIONS TO INITIALIZE STATE VARIABLES SHOULD BE PLACED. THIS IS NECESSARY ONLY IF THE INITIAL CONDITION IS COMPUTED, AND NOT ENTERED AS A PARAMETER.

THE SECOND COMMENT MARKS WHERE THE STATEMENTS TO COPY THE VALUES FROM THE SECONDARY VARIABLES TO THE STATE VARIABLES SHOULD BE PLACED. THIS WILL INITIALIZE THE VALUES OF THE STATE VARIABLES AT THE START OF EACH TIME STEP.

THE THIRD COMMENT MARKS WHERE THE STATEMENTS TO DO THE MODEL COMPUTATIONS SHOULD BE PLACED. THE ONLY CONSTRAINT ON THE ORDERING OF THE FORTRAN STATEMENTS IS THAT A VARIABLE THAT IS BEING COMPUTED, MUST BE COMPUTED BEFORE IT IS USED.

THE COMPUTATIONS MAY CONTAIN ANYTHING THAT IS LEGAL IN FORTRAN, EXCEPT USING PROGRAMS 10, 11, OR 15. THE MODEL WILL RUN AS PROGRAM 15.

THE %MODEL SCENARIO ANALYSIS PACKAGE - BASIC DEFINITIONS

BASIC DEFINITIONS

THE ENTIRE PACKAGE USES THE FOLLOWING DEFINITIONS. THERE ARE VERY FEW EXCEPTIONS TO THESE RULES AND THEY WILL BE COVERED IN THE DESCRIPTION OF THE STATEMENTS THAT BREAK THE RULES.

SYMBOLS: SYMBOLS ARE MADE UP OF AT LEAST ONE ALPHABETIC CHARACTER (A-Z) FOLLOWED BY ANY NUMBER (0-79) OF THE LETTERS A-Z, THE DIGITS 0-9, AND <>[]\/*+%. IF THE SYMBOL IS MORE THAN 6 CHARACTERS LONG, THEN ONLY THE FIRST 6 WILL BE USED. VARIABLE NAMES FROM THE MODEL CAN CONTAIN ONLY LETTERS AND DIGITS.

SAMPLE: A A2 LB/HR A10**8

SYMBOLS MAY COME EITHER FROM THE MODEL OR CAN BE ENTERED DIRECTLY. SYMBOLS FROM THE MODEL ARE NORMALLY VARIABLE NAMES, EITHER SIMPLE OR SUBSCRIPTED. THEY MAY ALSO COME FROM EQUIVALENCE STATEMENTS, BUT THEY MUST BE USED IN AN EXPRESSION SOMEWHERE IN THE MODEL. SYMBOLS MAY ALSO BE ADDED DIRECTLY TO PERMIT GIVING SYMBOLIC NAMES TO SUBSCRIPTS OR OTHER SPECIAL PURPOSES, LIKE LABELING UNITS.

INTEGERS INTEGERS ARE MADE UP OF DIGITS ONLY, AND CAN HAVE A - SIGN. LEADING ZEROS WILL BE IGNORED. THE FIRST NON-DIGIT WILL TERMINATE THE INTEGER.

THE $MODEL SCENARIO ANALYSIS PACKAGE - BASIC DEFINITIONS

REALS   REAL NUMBERS MAY HAVE ANY OF THE FOLLOWING FEATURES:

1 DECIMAL POINT

AN EXPONENT INDICATOR (E&↑) AND EXPONENT

IF E IS USED, IT MUST BE PRECEDED BY A DIGIT.

A - SIGN PRECEDING THE NUMBER

A - SIGN PRECEDING THE EXPONENT

SOME BLANKS FOLLOWING THE EXPONENT INDICATOR

1.0   1.   .1   1E 3   .00164   ↑2

REPEAT FACTORS - EITHER SYMBOLS OR REAL NUMBERS MAY BE FOLLOWED BY A REPEAT FACTOR OF THE FORM:

A:2   1.0:5   AB12:   3:

THE INTEGER FOLLOWING THE COLON SPECIFIES THE NUMBER OF TIMES THE ITEM IS TO BE REPEATED. IF IT IS MISSING, THEN THE MAXIMUM NUMBER NECESSARY WILL BE USED.

SIMPLE LISTS - SIMPLE LISTS ARE MADE UP OF A SERIES OF SYMBOLS AND/OR INTEGERS EITHER WITH OR WITHOUT REPEAT FACTORS. THEY MAY BE SEPARATED BY COMMAS OR BLANKS OR NOTHING, IF NO AMBIGUITIES RESULT. THE MAXIMUM LENGTH IS 11 ITEMS. EXAMPLES ARE:

A:3,B:4 C:

D,1 2 3:2

1,2,3,4 5 6 7,8,9,10,11

COMPOUND LISTS - COMPOUND LISTS CONSIST OF A SERIES OF COMPOUND LIST ELEMENTS, THAT MAY BE ANY OF THE FOLLOWING:

THE $MODEL SCENARIO ANALYSIS PACKAGE - BASIC DEFINITIONS

(SIMPLE LIST)

SYMBOL OR INTEGER (WITH OR WITHOUT REPEAT FACTOR)

$AN LIST SPECIFICATION (SEE LIST COMMENT)

#N FOR LIST SPECIFICATION (SEE FOR COMMENT)

AGAIN THE LIST ELEMENTS MAY BE SEPARATED BY COMMAS, BLANKS OR NOTHING, IF NO AMBIGUITY RESULTS. $AN OR #N FORMS MAY ALSO APPEAR IN SIMPLE LISTS THAT ARE PART OF A COMPOUND LIST, IN ADDITION TO SYMBOLS AND INTEGERS. A 0 (ZERO) APPEARING IN A SIMPLE LIST IN THIS CONTEXT WILL BE INTERPRETED AS A NULL ENTRY, PRINTED AS A BLANK, AND WILL ONLY PRESERVE ITS POSITION IN THE LIST. SOME EXAMPLES OF COMPOUND LISTS ARE:

```
Y:,$A
Y:,(NAM,WEUR,JAP,RDEV,EEUR)
(Y:5,YTOT)(NAM,WEUR,JAP,RDEV,EEUR,0)
```

THE WAY A COMPOUND LIST IS INTERPRETED IS THAT THE LOCATION OR INDEX OF EACH ITEM IN A COMPOUND LIST ELEMENT IS ADDED TO THE CORRESPONDING INDICIES OF OTHER COMPOUND LIST ELEMENTS. THIS MAKES POSSIBLE SUBSCRIPTING OR OTHER OPERATIONS. THE MAXIMUM NUMBER OF COMPOUND LIST ELEMENTS IS 10. WHEN WORKING WITH ARRAYS WITH TWO OR MORE SUBSCRIPTS, ALL SUBSCRIPTS MUST BE MULTIPLIED BY THE TOTAL RANGE OF VALUES OF ALL SUBSCRIPTS TO THE LEFT OF THE CURRENT ONE. A COMPOUND LIST ONLY ADDS, SO SOME CARE IS NECESSARY TO COMPUTE SUBSCRIPTS PROPERLY.

THE $MODEL SCENARIO ANALYSIS PACKAGE - BASIC DEFINITIONS

VALUE LIST - A VALUE LIST IS A SERIES OF REAL NUMBERS OR INTEGERS, WITH OR WITHOUT REPEAT FACTORS, AND MAY BE SEPARATED BY COMMAS, BLANKS, OR NOTHING IF NO AMBIGUITIES ARISE.

TITLES - A TITLE MAY BE STORED BY ENCLOSING IT IN SINGLE QUOTES, LIKE: 'TITLE'. THE MAXIMUM LENGTH IS 60 CHARACTERS. ONCE A TITLE IS DEFINED, IT WILL REMAIN UNTIL A NEW ONE IS SPECIFIED.

PLOT CHARACTERS - THE CHARACTERS TO USE FOR THE PRINTER PLOTS ARE ENCLOSED IN DOUBLE QUOTES, LIKE: "PLOT". THE PLOT CHARACTERS ARE STORED, AND WILL REMAIN UNTIL A NEW SET IS SPECIFIED.

INPUT FORMATTING - IN GENERAL - THE INPUT IS IN FREE FORMAT WITH EACH STATEMENT BEING ON A SEPARATE LINE. IF MORE THAN ONE STATEMENT ON A LINE IS DESIRED, THEN ALL BUT THE RIGHT MOST STATEMENT SHOULD BE FOLLOWED BY EXCLAMATION POINTS (!). IF NO AMBIGUITY WOULD RESULT FROM THE OMISSION OF AN !, THEN IT CAN BE OMITTED. A COMMENT CAN BE PUT ON A LINE, OR A STATEMENT CAN BE CONTINUED ON THE NEXT LINE BY PUTTING A SEMI-COLON (;) IN THE LINE. THAT PORTION OF THE LINE TO THE RIGHT OF THE ; WILL BE IGNORED AND SCANNING CONTINUED ON COLUMN ONE OF THE NEXT LINE. A SEMICOLON OR THE LAST COLUMN OF A LINE TERMINATES WHATEVER SYMBOL, REAL NUMBER, OR INTE-

GER IS BEING SCANNED. THEY ARE NOT CONTINUED ON THE NEXT LINE. IF A SEMI-COLON APPEARS IN COLUMN ONE, THEN THE NEXT LINE PRINTED WILL BE AT THE TOP OF A PAGE.

THE $MODEL SCENARIO ANALYSIS PACKAGE - THE $DICT PROGRAM

THE $DICT PROGRAM

THE COMMANDS TO THE $DICT PROGRAM ARE DIVIDED INTO THE FOLLOWING FOUR CLASSES:

1 CONTROL PARAMETERS
2 PRINT OPTIONS
3 MISCELANEOUS
4 RUN

CONTROL PARAMETER STATEMENTS

CONTROL PARAMETERS ARE USED TO CONTROL THE OVERALL OPERATION OF THE PACKAGE. THEY ARE SPECIFIED IN STATEMENTS OF THE FORM:

SYMBOL = INTEGER!

BOTH THE = SIGN AND ! ARE OPTIONAL AND MAY BE OMITTED. THE SYMBOL MAY BE ANY OF THE FOLLOWING:

TABNUM - SPECIFIES THE DATA TABLE NUMBER WHERE THE DICTIONARY AND COMMANDS ARE STORED. THIS DATA TABLE MUST BE AT LEAST 4096 LONG.

PGMNUM - THE PROGRAM NUMBER TO USE FOR THE MODEL. IT WILL BE

RTLINKED TO EVERY TIME IT IS RUN.

FIRSTDT - THE VALUE OF THE FIRST TIME STEP.

LASTDT - THE VALUE OF THE LAST TIME STEP. THE TOTAL NUMBER OF TIME STEPS (NDT) = LASTDT-FIRSTDT+1. IT IS NOT ADVISIBLE TO CHANGE EITHER FIRSTDT OT LASTDT AFTER THE PARAMETERS HAVE BEEN ENTERED OR THE MODEL HAS BEEN RUN. THE ONLY CHANGE THAT HAS MUCH USE WILL BE TO REDUCE LASTDT.

NOTE THE TOTAL NUMBER OF TIME STEPS (NDT) MUST BE LESS THAN 11?.

ALL OF THE CONTROL PARAMETERS ARE STORED IN THE DATA TABLE, AND DO NOT NEED TO BE RESET, ONCE THEY ARE ESTABLISHED. THE TABNUM = COMMAND MUST BE THE FIRST THING IN DECK. NOTHING ELSE WILL BE ACCEPTED UNTIL IT IS SPECIFIED.

PRINT OPTIONS

THE PRINT OPTIONS COMMAND HAS THE FOLLOWING FORMS:

PRINT OPTION

PRINT OPTION, OPTION

PRINT OPTION, OPTION, OPTION

PRINT OPTION, OPTION, OPTION, OPTION

WHERE OPTION REFERS TO ONE OF:

ALL - PRINT ALL SYMBOLS USED BY THE PROGRAM. SOME OF THE SYMBOLS ARE USED INTERNALLY BY THE FORTRAN COMPILER, SOME REFER TO LABEL NUMBERS. ALSO INCLUDED ARE THE SYMBOLS FOR VARIABLES BOTH IN COMMON AND OTHERWISE. THIS MAKES IT POSSIBLE TO CHECK IF SOME VARIABLES HAVE NOT BEEN PLACED IN COMMON, BUT SHOULD HAVE BEEN.

NEW - A SYMBOL HAS BEEN FOUND THAT WAS NOT IN THE DICTIONARY. IT WILL BE ADDED TO THE DICTIONARY AND, IF THIS OPTION HAS BEEN SPECIFIED, THEN IT WILL BE PRINTED.

CHANGES - A SYMBOL HAS DIFFERENT LOCATION OR INDEX IN THIS RUN FROM ITS VALUE STORED IN THE DICTIONARY. IT WILL BE CHANGED TO THE NEW VALUE AND, IF THIS OPTION WAS SPECIFIED, THEN THE SYMBOL WITH BOTH NEW AND OLD VALUES WILL BE PRINTED.

SYMBOLS - AT THE END OF THE RUN PRODUCE A PRINTOUT OF THE SYMBOLS IN THE DICTIONARY. THE LISTING WILL SHOW THE SYMBOLS IN THREE DIFFERENT ORDERS; AS THEY WERE ENTERED, BY INCREASING VALUE, AND ALPHABETICAL ORDER.

THE PRINT OPTION COMMAND SPECIFIES WHICH PRINT OPTIONS TO USE WHEN THE ACTUAL RUN IS MADE. IT DOES NOT PRINT ANYTHING IM-

MEDIATELY. THE COMMAS ARE OPTIONAL AND MAY OMITTED.

MISCELANEOUS COMMANDS

THE MISCELANEOUS COMMANDS HAVE THE FORMS:

CLEAR !
STOP !

THE EXCLAMATION POINT IS OPTIONAL AND MAY BE OMITTED. THE COMMANDS DO THE FOLLOWING:

CLEAR - REMOVES ALL SYMBOLS FROM THE DICTIONARY, INCLUDING COMMANDS, AND RESETS THE COMMAND STORAGE POINTERS.

STOP - TERMINATES EXECUTION OF THE $DICT PROGRAM AND WRITES THE COMPLETED DICTIONARY ON DISC. IF THIS COMMAND IS NOT GIVEN, THEN THE DICTIONARY WILL NOT BE SAVED.

THE RUN COMMAND

THE RUN COMMAND HAS THE FORM:

THE $MODEL SCENARIO ANALYSIS PACKAGE - THE $DICT PROGRAM

RUN SYMBOL = I, SYMBOL = I !

THE SYMBOLS WILL BE ADDED TO THE DICTIONARY WITH THE VALUES OF THE INTEGERS SPECIFIED. THE EQUAL SIGNS AND COMMAS ARE OPTIONAL, AND MAY BE OMITTED. THE NORMAL USE OF THE SYMBOLS IS TO GIVE SYMBOLIC NAMES TO SUBSCRIPTS OR AS UNITS LABELS. THIS MAKES THE USE OF SUBSCRIPTED VARIABLES EASIER AND CLEARER. THE EXCLAMATION POINT IS OPTIONAL, BUT IF OMITTED THEN THE LAST SYMBOL, IF ANY ARE SPECIFIED, MUST BE FOLLOWED BY A BLANK CARD. IF ANY PRINT OPTIONS WERE SPECIFIED, THEN THEY ARE PERFORMED DURING THE RUN COMMAND.

ALL COMMANDS TO THE $DICT PROGRAM ARE READ IN FROM CARDS, AND WILL NORMALLY FOLLOW A COMPILE. IF A RUN COMMAND IS GIVEN WITHOUT A COMPILE IMMEDIATELY BEFORE THE RUN, THEN GARBAGE CAN BE ADDED TO THE DICTIONARY. IF IT IS DESIRED TO LIST THE CURRENT CONTENTS OF THE DICTIONARY, THEN COMPILE A STOP CARD FIRST, AND RUN $DICT. THIS PROGRAM CAN ALSO BE USED TO CHECK THE COMMON STATEMENTS OF ANY MAIN PROGRAM OR SUBROUTINE.

THE $MODEL SCENARIO ANALYSIS PACKAGE - THE $MODEL PROGRAM

THE $MODEL PROGRAM

THE COMMANDS TO THE $MODEL PROGRAM ARE DIVIDED INTO THE FOLLOWING FOUR CLASSES:

1 CONTROL PARAMETERS

2 COMAND LANGUAGE

3 MISCELANEOUS

MODEL. THESE COMMANDS DO THE ACTUAL USEFUL WORK OF THE PACKAGE.

PARAMETER INPUT COMMAND

THE FORMS OF THE PARAMETER INPUT COMMANDS ARE:

PARAMETER COMPOUND LIST=VALUE LIST!

PAR COMPOUND LIST=VALUE LIST!

THE COMPOUND LIST IS DESCRIBED IN THE BASIC DEFINITIONS, AND SPECIFIES WHAT VARIABLES ARE TO RECEIVE THE VALUES. THE EQUAL SIGN IS NOT OPTIONAL AND MUST BE IN ITS PROPER PLACE. THE VALUE LIST IS ALSO DESCRIBED IN THE BASIC DEFINITIONS. THIS COMMAND WILL GO ON TO THE NEXT OR SUCCEEDING LINES TO TO GET A VALUE LIST AS LONG AS THE INPUT LIST. SEMI-COLONS ARE NOT NEEDED TO FORCE A CONTINUATION ON THE NEXT LINE.

TIME SERIES INPUT COMMAND

THE FORM OF THE TIME SERIES INPUT COMMANDS:

SERIES COMPOUND LIST=SERIES VALUE LIST!

THE COMPOUND LIST IS DESCRIBED IN THE BASIC DEFINITIONS, AND THE EQUAL SIGN MUST BE PRESENT. THE SERIES VALUE LIST ALLOWS REALS AND INTEGERS, EITHER WITH OR WITHOUT REPEAT FACTORS, OR A SPECIAL FORM:

REAL @ INTEGER

THE REAL NUMBER MUST HAVE A REPEAT FACTOR OF 1, AND THE AT SIGN MUST BE INCLUDED. THE REAL NUMBER MAY BE AN INTEGER. THE INTEGER REFERS TO THE SIMULATION TIME WHEN THE VALUE WILL TAKE EFFECT. IF THE TIME SERIES HAS NOT BEEN FILLED TO THAT SIMULATED TIME, THEN LINEAR INTERPOLATION FROM THE LAST VALUE SUPPLIED WILL BE USED TO FILL IN THE MISSING VALUES. THE INTEGER MUST BE BETWEEN FIRSTDT PLUS THE NUMBER OF VALUES ALREADY SPECIFIED, AND LASTDT+1. IF AN INDEFINTE REPEAT FACTOR IS USED, THEN IT WILL BE SET TO COMPLETE THE CURRENT SERIES. A DEFINITE REPEAT FACTOR MAY NOT BE USED TO SPECIFY VALUES THAT GO BEYOND ONE TIME SERIES, INTO ANOTHER TIME SERIES. THE VALUES ARE NOT PRINTED WHEN THEY ARE ENTERED, BUT MAY BE PRINTED WITH A PRINT COMMAND. THIS COMMAND WILL GO ON TO THE NEXT OR SUCCEEDING LINES IN ORDER TO GET A VALUE LIST AS LONG AS IS NECCESSARY. SEMI-COLONS ARE NOT NEEDED TO FORCE A CONTINUATION ONTO THE NEXT LINE.

PRINT COMMAND

THE FORM OF THE PRINT COMMAND IS:

PRINT COMPOUND LIST!

THE COMPOUND LIST IS DESCRIBED IN THE BASIC DEFINITIONS. THE TITLE WILL BE PRINTED AT THE TOP OF THE PAGE, AND MAY BE DESCRIBED ANYWHERE, AS IN THE BASIC DEFINITIONS. THE NUMBERS WILL BE PRINTED UNDER AN F FORMAT THAT IS COMPUTED TO MAINTAIN ABOUT 6 SIGNIFICANT FIGURES. IF THE NUMBERS ARE EITHER TOO LARGE OR SMALL THEN E FORMATS WILL BE USED.

PUNCH COMMAND

THE FORM OF THE PUNCH COMMAND IS:

PUNCH COMPOUND LIST!

THE COMPOUND LIST IS DESCRIBED IN THE BASIC DEFINITIONS. THE TITLE WILL BE PUNCHED, FOLLOWED ALL VALUES OF EACH VARIABLE IN TURN. THE CARDS MAY BE READ IN AS A TIME SERIES OR UNDER A FORTRAN 8E10.0 FORMAT.

THE PLOT COMMANDS

THE FORM OF THE PLOT COMMANDS IS:

PLOT SCALING LIST COMPOUND LIST!

XYPLOT SCALING LIST COMPOUND LIST!

THE COMPOUND LIST IS DESCRIBED IN THE BASIC DEFINITIONS. PLOT PRODUCES A PLOT ACCROSS THE PAGE ON THE LINE PRINTER, WITH A MAXIMUM OF 8 VARIABLES. XYPLOT PRODUCES THE INDENTIFICATION ON THE LINE PRINTER AND THE PLOT ON THE XYPLOTTER. THE SCALING LIST HAS THE FOLLOWING FORMS:

SCALE VALUE
SCALE TYPE
SCALE TYPE, SCALE VALUE
SCALE VALUE, SCALE TYPE

THE SCALE VALUE HAS THE FOLLOWING FORMS:

AUTO
MAXMIN
SPECIFIED SPECIFICATION LIST
OLD

THIS OPTION SPECIFIES HOW THE SCALE FACTORS WILL BE DERIVED.

AUTO — SETS THE MINIMUM TO ZERO AND THE MAXIMUM TO THE SMALLEST VALUE THAT RESULTS IN EACH DIVISION BEING 1, 2, OR 5 TIMES A POWER OF TEN, AND REMAIN ON SCALE.

MAXMIN — SETS THE MINIMUM VALUE TO THE DATA MINIMUM, AND THE MAXIMUM VALUE TO THE DATA MAXIMUM.

OLD KEEP THE PREVIOUS VALUES.

SPECIFIED SPECIFY THE SCALE FACTORS. THE SPECIFICATION LIST HAS THE FOLLOWING FORMS:

SPEC LIST

(SPEC LIST),(SPEC LIST)

IN THE FIRST FORM, THE FIRST 8 VALUES ARE THE MAXIMUMS, AND THE SECOND 8 ARE THE MINIMUMS. IN THE SECOND FORM, EACH SET IS ENCLOSED IN PARENTHESIS, AND EITHER MAY BE LESS THAN 8 LONG. IF ANY ITEMS ARE OMITTED, THEN THE VALUES WILL BE SET TO ZERO.

A SPEC LIST IS MADE UP OF A SERIES OF REAL NUMBERS,

4 INPUT/OUTPUT

CONTROL PARAMETER STATEMENTS

CONTROL PARAMETERS ARE USED TO CONTROL THE OVERALL OPERATION OF THE PACKAGE. THEY ARE SPECIFIED IN STATEMENTS OF THE FORM:

SYMBOL = INTEGER!

BOTH THE = SIGN AND ! ARE OPTIONAL AND MAY BE OMITTED. THE SYMBOL MAY BE ANY OF THE FOLLOWING:

TABNUM - SPECIFIES THE DATA TABLE NUMBER WHERE THE DICTIONARY AND COMMANDS ARE STORED. THIS DATA TABLE MUST BE AT LEAST 4096 LONG.

PGMNUM - THE PROGRAM NUMBER TO USE FOR THE MODEL. IT WILL BE RTLINKED TO EVERY TIME IT IS RUN.

FIRSTDT - THE VALUE OF THE FIRST TIME STEP.

LASTDT - THE VALUE OF THE LAST TIME STEP. THE TOTAL NUMBER OF TIME STEPS (NDT) = LASTDT-FIRSTDT+1. IT IS NOT ADVISIBLE TO CHANGE EITHER FIRSTDT OT LASTDT AFTER THE PARAMETERS HAVE BEEN ENTERED OR THE MODEL HAS BEEN RUN. THE ONLY CHANGE THAT HAS MUCH USE WILL BE TO REDUCE LASTDT.

NOTE THE TOTAL NUMBER OF TIME STEPS (NDT) MUST BE LESS THAN 112.

ALL OF THE CONTROL PARAMETERS ARE STORED IN THE DATA TABLE, AND DO NOT NEED TO BE RESET, ONCE THEY ARE ESTABLISHED. THE TABNUM = COMMAND MUST BE THE FIRST THING IN DECK. NOTHING ELSE WILL BE ACCEPTED UNTIL IT IS SPECIFIED.

COMMAND LANGUAGE STATEMENTS

COMMAND LANGUAGE STATEMENTS ARE USED TO SIMPLIFY THE SETUP AND CONTROL OF LARGE, COMPLEX OPERATIONS. THERE ARE THREE SETS OF COMMANDS; LIST SPECIFICATION, COMMAND STORAGE AND EXECUTION, AND LOOPING.

THE LIST SPECIFICATION STATEMENT HAS THE FOLLOWING FORM:

LIST $AN=SIMPLE LIST!

THE ! MAY BE OMITTED IF THERE IS NOTHING ELSE AFTER THE SIMPLE LIST ON THIS LINE. THE $AN IS A DOLLAR SIGN FOLLOWED BY ONE LETTER OR DIGIT. THIS MAKES 36 LISTS AVAILABLE FOR USE.

THE COMMAND STORAGE STATEMENTS HAVE THE FORMS:

COMMAND SYMBOL BODY ENDCOM!

DO SYMBOL!

COMMAND PURGE SYMBOL!

COMMAND PRINT SYMBOL!

THE FIRST FORM STORES THE COMMAND NAME IN THE COMMAND DICTIONARY, AND THE BODY OF THE COMMAND IN THE DATA TABLE. COMMAND NAMES MUST NOT DUPLICATE EXISTING COMMANDS. THE BODY OF THE COMMAND CAN CONTAIN ANY NUMBER OF STATEMENTS EXCEPT ANOTHER COMMAND DEFINITION. SOME COMMANDS, LIKE TYPE OR READ, HAVE COMPLEX, THOUGH PREDICTABLE, RESULTS. THE BODY OF THE COMMAND ENDS ON THE FIRST APPEARENCE OF THE SYMBOL ENDCOM (ENDCOMMAND).

THE SECOND FORM IS USED TO EXECUTE A STORED COMMAND. THE SYMBOL MUST BE DEFINED IN THE COMMAND DICTIONARY. IF THE INPUT IS FROM EITHER CARDS OR TYPEWRITER, AND NOT FROM ANOTHER COMMAND, THEN THE REST OF THE LINE FOLLOWING THE SYMBOL WILL BE IGNORED.

IF AN ERROR OCCURS DURING A COMMAND, THEN THE COMMAND WILL BE TERMINATED, AND NEW LINE WILL BE READ FROM THE CURRENT INPUT DE- VICE.

THE THIRD FORM IS USED TO REMOVE A SINGLE COMMAND FROM THE COMMAND DICTIONARY. THE SYMBOL MUST BE A COMMAND NAME THAT IS ALREADY IN THE DICTIONARY. THE COMMAND IS NOT PHYSICALLY REMOVED, SO ANY STORAGE SPACE USED BY THE COMMAND IS NO LONGER AVAILABLE. IF THE STORAGE REMAINING IN THE DATA TABLE IS TOO SMALL FOR LOOP COMMANDS, THEN IT WILL BE NECCESSARY TO DO A PURGE TO CLEAR ALL THE COMMAND STORAGE.

THE FOURTH FORM PRINTS A LISTING OF THE COMMAND AS IT IS STORED ON DISC. THIS IS USEFUL TO FIND OUT WHAT HAS BEEN STORED. THE REST OF THE LINE FOLLOWING THE SYMBOL WILL BE IGNORED.

THE EXCLAMATION POINTS ARE OPTIONAL AND MAY BE OMITTED.

THE LOOPING COMMAND HAS THE FORM:

FOR #N=COMPOUND LIST!BODY!END

THE N REFERS TO THE FOR LOOP NUMBER. IN THE OUTER LOOP IT HAS A VALUE OF 1, AND INCREASES BY 1 FOR EACH LOOP IN THE NEST. LOOPS MAY BE NESTED TO 10 LEVELS MAX. THE WAY THE COMMAND WORKS IS THE LOOP INDEX IS A LIST THAT TAKES ON THE VALUES OF EACH COMPOUND LIST ELEMENT FOR A RUN THROUGH THE COMMAND BODY. THE RESULT IS THAT THE BODY IS DONE AS MANY TIMES AS THERE ARE COMPOUND LIST ELEMENTS, WITH A LIST THAT IS DIFFERENT FOR EACH EXECUTION. THE EXCLAMATION POINTS MAY BE OMITTED IF THERE IS NOTHING REMAINING ON THE LINE. IF THE ORIGINAL INPUT DEVICE WAS THE CARD READER OR

TYPEWRITER, THEN ANYTHING FOLLOWING THE OUTERMOST END WILL BE LOST.

MISCELANEOUS COMMAND STATEMENTS

THE MISCELANEOUS COMMANDS DO A NUMBER OF DIFFERENT THINGS, BUT ALL REQUIRE NO ADDITIONAL INFORMATION OTHER THAN THE COMMAND WORD. THE FORM OF ALL MISCELANEOUS COMMANDS IS:

COMMAND!

THE EXCLAMATION POINT IS OPTIONAL AND CAN BE LEFT OUT. THE COMMANDS ARE AS FOLLOWS:

LOG - LIST EVERY INPUT LINE IN THE OUTPUT LISTING. THIS IS USEFUL WHEN LOADING COMMANDS INTO THE DATA TABLE TO VERIFY WHAT WAS ENTERED. ON INITIAL ENTRY, THIS LISTING IS TURNED OFF.

NOLOG - TURNS OFF THE LISTING OF ALL INPUT LINES, THAT WAS TURNED ON BY LOG.

NOPAR - TURNS OFF THE LISTING OF PARAMETERS AND VALUES WHEN THEY ARE EXECUTED. THIS MODE IS RESET BY A RUN COMMAND.

TYPE - AT THE END OF THE CURRENT INPUT LINE, START READING FROM THE TYPEWRITER. IF THIS COMMAND IS EXECUTED FROM EITHER A FOR LOOP OR STORED COMMAND, THEN THE REST OF

THE INPUT MUST MATCH THE COMMAND.

READ - AT THE END OF THE CURRENT INPUT LINE, START READING FROM THE CARD READER. IF THIS COMMAND IS EXECUTED FROM EITHER A FOR LOOP OR STORED COMMAND, THE REST OF THE INPUT MUST MATCH THE COMMAND. ON INITIAL ENTRY, INPUT IS FROM THE CARD READER, AND AT LEAST THE TABNUM= COMMAND MUST BE GIVEN FROM CARDS.

DESCRIBE - PRINTS A PAGE SHOWING THE CURRENT VALUES OF ALL LISTS AND THE NAMES OF ALL STORED COMMANDS.

PURGE - DELETES ALL THE CURRENT STORED COMMANDS AND RESETS THE STORAGE PRINTER.

STOP - EXIT FROM THE PACKAGE. IF ANY NEW STORED COMMANDS WERE ADDED, OR ANY LISTS CHANGED, THEN THE NEW STATUS WILL BE STORED IN THE DATA TABLE. IF THIS COMMAND IS NOT EXECUTED, THEN THE CHANGES WILL NOT BE MADE IN THE DATA TABLE.

RUN - RUN THE MODEL. THE MODEL IS ONLY RUN WHEN THIS COMMAND IS GIVEN, SO IF PARAMETERS ARE CHANGED, THEN A RUN COMMAND IS NECESSARY TO PRINT OR PLOT THE RESULTS.

THE $MODEL SCENARIO ANALYSIS PACKAGE - THE $MODEL PROGRAM

INPUT/OUTPUT COMMAND STATEMENTS

THE INPUT/OUTPUT COMMANDS ARE USED TO GET PARAMETERS AND TIME SERIES INTO THE MODEL, AND PRODUCE PRINTS AND PLOTS FROM THE

WITH OR WITHOUT REPEAT FACTORS , AND MAY ALSO CONTAIN THE SPRCIAL SYMBOLS # AND @. A # SIGN HAS THE VALUE OF THE APPROPRIATE MAXIMUM OR MINIMUM VALUE. AN @ SIGN HAS THE VALUE OF FIRSTDT OR LASTDT FOR MINIMUM OR MAXIMUM VALUES.

THE SCALE TYPE HAS THE FOLLOWING FORMS:

COMMON
INDEPENDANT

THE FIRST FORM SETS THE SAME SCALE FACTOR FOR ALL VARIABLES, WHILE THE SECOND LEAVES THEM AS THEY WERE. THE COMMON SCALE FACTOR WILL BE SUCH THAT ALL PLOTS WILL FIT ON THE SAME PAGE. TWO OTHER OPTIONS CAN BE SPECIFIED IF THE PLOT IS TO BE MADE ON THE XY PLOTTER. AXIS WILL CAUSE AN AXIS WITH TICK MARKS TO BE DRAWN. XY WILL CAUSE ALL BUT THE LAST VARIABLE TO BE PLOTTED WITH RESPECT TO THE LAST VARIABLE.

IF A SCALE TYPE OR SCALE VALUE IS NOT SPECIFIED, THEN AUTO

OR INDEPENDANT WILL BE ASSUMED.

ERROR MESSAGES

THERE ARE TWO TYPES OF ERROR MESSAGES IN THE PACKAGE. THE SIMPLEST SIMPLY PRINTS THE CURRENT INPUT LINE, (THE LINE MAY BE FROM A STORED COMMAND OR LOOP) AND POINTS TO THE END OF THE ITEM THAT CAUSED THE ERROR. THE ACTUAL MISTAKE MAY BE FAR BEHIND THE POINTER. MOST OF THE LESS OBVIOUS ERRORS WILL ALSO PRINT AN ERROR NUMBER. THESE ERROR NUMBERS MAY THEN BE LOOKED UP IN THE FOLLOWING TABLE.

ERROR MESSAGE NUMBERS

-	ERRORS ARE FATAL AND GIVE AN IMMEDIATE STOP
1	UNDEFINED COMMAND SYMBOL
2	TABNUM MUST BE DEFINED FIRST
-3	ILLEGAL DATA TABLE NUMBER
-4	DATA TABLE NOT PROPERLY COMPILED
-5	DATA TABLE NOT INITIALIZED BY $DICT
6	LIST TOO LONG IN LIST DEFINITION
-7	DUPLICATE COMMAND NAME
-8	DICTIONARY OVERFLOW ON ADDING COMMAND
-9	DATA TABLE OVERFLOW ON ADDING COMMAND
10	ENDCOM GIVEN WHEN NOT PROCESSING COMMAND
11	UNDEFINED COMMAND NAME
-12	TOO MANY COMMAND LEVELS

-13	FOR LOOPS MUST BE NESTED IN ORDER
-14	FOR LOOPS NESTED TOO DEEP (10 MAX)
-15	DATA TABLE STORAGE EXCEEDED ON FOR LOOP
-16	END ENCOUNTERED WITHOUT FOR
17	UNDEFINED SYMBOL IN LIST DECLARATION
18	UNDEFINED SYMBOL
19	LIST TOO LONG (11 MAX)
20	FOR LIST NUMBER TOO LARGE OR SMALL
21	TOO MANY LISTS SPECIFIED (10 MAX)
-22	SYMBOL CONVERSION CALL ILLEGAL FOR SERIES
23	PARAMETER VALUE LIST TOO LONG OR SHORT
-24	BAD COMMAND EXECUTION
-25	UNRECOVERABLE COMMAND OR FOR ERROR
26	REPEAT FACTOR RAN BETWEEN SERIES
27	@ BEFORE CURRENT DT
28	@ BEYOND LAST DT
29	RUN ATTEMPTED WITHOUT PAR OR SERIES
30	WRONG NUMBER OF SCALE FACTORS

VI.8. COORDINATION PRINCIPLES FOR SYSTEM INTERACTIONS

J. Takahara

April 1974

1. Introduction

A complex large scale system is a today's main topic of system engineering and many useful and practical results have been found for it. However, most of considerations of complex large scale systems have been made in informal frameworks. In this paper we try to treat complex systems in an axiomatic way to yield a solid foundation to the concept of interaction and consider coordination principles for system interaction.

2. Definition of a Complex System

We start from the definition of goal seeking systems. A goal seeking system consists of a goal seeker, which will be referred as decision maker, and a process to be controlled by the decision maker. Let M, X and Y be the sets of manipulating variables, uncertainty inputs and outputs of the process, respectively. Then the process is expressed by the mapping P :

$$P : M \times X \longrightarrow Y$$

If an initial condition of the process is fixed, a dynamical process is represented by the above expression. In this paper we always assume that when a dynamical process is considered, its initial condition is fixed. Furthermore, we assume that the uncertainty set X is a singleton set. This assumption may be considered too artificial to treat complex large scale systems. However, since the purpose of this paper is to clarify the concept of interaction, it is desirable to simplify the model by deleting not directly related complexities. When the uncertainty set is neglected, the process can be exprened by

$$P : M \longrightarrow Y \tag{1}$$

A decision maker is characterized by his goal (or objective function) and his decision principle. Since the uncertainty is neglected, the objective function G can be represented by

$$G : M \times Y \longrightarrow R \tag{2}$$

where R is the set of real numbers. The objective function may be defined in more general forms but we choose the simplest one because of the same reason as for the uncertainty set . The decision principle is the principle to choose a decision among alternatives. Satisfaction approach and optimization are typical examples of decision principles for certainty. Let D be a decision principle of the decision maker, then, a goal seeking system is represented by (P, G, D).

The type of a complex system we consider in this paper is the one which consists of a finite number of goal seeking subsystems. A political or economical model of the world or models of enterprises are typical examples of this kind of complex systems. Suppose the complex system consists of n subsystems where the i-th subsystem is expressed by (P_i, G_i, D_i). The expressions of the subsystems are the same as the goal seeking system given by Eq.(1) and (2) except that the subsystems should include the effect of interactions among them. Let U_i be the set of interactions to the i-th subprocess from the others. Then, P_i is formally given by :

$$P_i : M_i \times U_i \longrightarrow Y_i \tag{3}$$

It should be noticed that the existence of U_i can be explicitly recognized but that the expression of U_i is not unique though M_i and Y_i are uniquely specified. Let us consider the following example. Let

$$y_1 = 10m_1 + y_2 \tag{4}$$

$$y_2 = 20m_2 + 2y_1 \tag{5}$$

where m_1, m_2, y_1 and y_2 are real numbers. If a complex system cosists of the above two subprocesses, the interactions are expressed by $u_1 = y_2$ and $u_2 = y_1$.

If Eq.(4) and (5) are solved for y_1 and y_2, we have

$$y_1 = -10m_1 - 20m_2 \tag{6}$$

$$y_2 = -20m_2 - 20m_1 \tag{7}$$

Eq.(6) and (7) also represent the same complex system as Eq.(4) and (5) while in Eq.(6) and (7) the interactions are represented by $u_1 = m_2$ and $u_2 = m_1$.

The above example shows that the interaction cannot be uniquely specified and its representation depends on how a system model is built or it may be said that a system model depends on how the interaction is specified. Consequently, the concept of interaction is considered to take the analogous role in the representation of a complex system as that of state in the representation of a dynamical system and so it is important for the mathematical system theory to characterize the concept of interaction in a logical way.

Since interaction is a secondary concept while manipulating and autput variables are primary, it is natural to try to define a subprocess S_i on M_i and Y_i rather than on M_i, U_i and Y_i. We take the following as the fundamental definition of a subprocess :

$$S_i \subset M_i \times Y_i \tag{8}$$

such that S_i is related to Eq. (3) in the following way.

$$(m_i, y_i) \in S_i \longleftrightarrow (\exists u_i \in U_i)(y_i = P_i(m_i, u_i) \;\&\; y_i \in Y_i \;\&\; m_i \in M_i) \tag{9}$$

It is easy to show that both representations by Eq. (4) and (5) and by Eq. (6) and (7) become equal each other when they are expressed in the form of (8).

Since a basic definition of a subprocess is given, a definition of a complex system can be introduced immediately.

Let $M \subset M_1 \times \cdots \times M_n$

and $Y \subset Y_1 \times \cdots \times Y_n$

be the sets of input and output of a complex system.

Then

Def. 1

A non empty relation

$$S \subset S_1 \times \cdots \times S_n \tag{10}$$

is called a complex process (system) where $S_i \subset M_i \times Y_i$ is referred to as the i-th subprocess of S.

Since $S_1 \times \cdots \times S_n$ is not a subset of $M \times Y$, the above definition is not precise. However, there is a natural one-to-one mapping ψ from $S_1 \times \cdots \times S_n$ into $M \times Y$ defined by

$$\psi((m_1, y_1), \ldots, (m_n, y_n)) = (m_1, \ldots, m_n, y_1, \ldots, y_n)$$

Rel. (10) should be understood through ψ.

3. Interaction

One of the fundamental questions of a complex system is whether its subprocesses are mutually dependent or not. When they are independent, its complexity may be nominal. When they are dependent, a usual procedure to do with it is to identify the dependency by interaction and to treat the system in terms of the interaction. In this section we consider how mutual dependency can be expressed for a complex system defined by (10) and how interaction is specified

Def.2

If a complex process S defined by (10) is a proper subset of $S_1 \times \cdots \times S_n$, then the subprocesses are said mutually dependent. Conversely, if $S = S_1 \times \cdots \times S_n$, they are mutually independent.

Before anlyzing Def.2 let us consider the example of a complex process given by Eq. (4) and (5). We have form Eq. (4) that

$$(1, 10) \in S_1 \text{ and } (1, 20) \in S_2$$

where $u_1 = 0$ and $u_2 = 6$. Consequently,

$$((1, 10), (1, 20)) \in S_1 \times S_2$$

However, Eq. (6) and (7) show that

$$((1, 1), (10, 20)) = \psi((1, 10), (1, 20)) \notin S$$

Therefore, S is a proper subset of $S_1 \times S_2$, that is, the processes of S are by definition mutually dependent.

This is compatible with our intuitive understanding of mutual dependency and interaction. Suppose Eq (4) and (5) are modified such that

$$y_1 = 10 m_1 \tag{11}$$

$$y_2 = 20 m_2 \tag{12}$$

Thenm,since

$$S_1 = \{(m_1, 10 m_1) \mid m_1 \in M_1\}$$

and

$$S_2 = \{(m_2, 20 m_2) \mid m_2 \in M_2\}$$

and since for every $(m_1, m_2) \in M_1 \times M_2$

$$(m_1, m_2, 10 m_1, 20 m_2) \in S$$

we have $S = S_1 \times S_2$, that is, the subprocesses given by Eq. (11) and (12) are by definition mutually independent. This is also compatible with our intuition.

Let

$$\mathcal{D}(S) = \{x \mid (\exists y)((x, y) \in S)\}$$

$$\mathcal{D}(S_i) = \{x_i \mid (\exists y_i)((x_i, y_i) \in S_i)\}$$

For the notational convenience we assume that $X = \mathcal{D}(S)$ and $X_i = \mathcal{D}(S_i)$. Then

Proposition 1

Suppose $\mathcal{D}(S) = \mathcal{D}(S_1) \times \cdots \times \mathcal{D}(S_n)$. Then, $S_1, \ldots, S_n$ are mutually independent if and only if $S_1, \ldots, S_n$ are functional.

Prof : Suppose $S_1, \ldots, S_n$ are mutually independent. Let $(\hat{x}_i, \hat{y}_i) \in S_i$ and $(\hat{x}_i, \hat{y}'_i) \in S_i$. Let $(x_j, y_j) \in S_j$ $(i \neq j)$ be arbitrary Since $S = S_1 \times \cdots \times S_n$, we have $(x_1, \ldots, \hat{x}_i, \ldots, x_n, y_1, \ldots, \hat{y}_i, \ldots, y_n)$

$\in S$ and $(x_1, \ldots, \hat{y}_i, \ldots, x_n, y_1, \ldots, \hat{y}'_i, \ldots, y_n) \in S$. Then, since S is functional, $\hat{y}_i = \hat{y}'_i$ holds, that is, S_i is a function. Conversely, suppose $S_1, \ldots, S_n$ are functions. Suppose S is a proper subset of $S_1 \times \cdots \times S_n$ such that $(x_1, \ldots, x_n, y_1, \ldots, y_n) \notin S$ and $((x_1, y_1), \ldots, (x_n, y_n)) \in S_1 \times \cdots \times S_n$. Since S is a function and since $\mathcal{D}(S) = \mathcal{D}(S_1) \times \cdots \times \mathcal{D}(S_n)$, there exists $(\hat{y}_1, \ldots, \hat{y}_n) \in Y_1 \times \cdots \times Y_n$ such that $(x_1, \ldots, x_n, \hat{y}_1, \ldots, \hat{y}_n) \in S$. Then $(x_i, \hat{y}_i) \in S_i$ for every i. Since $(x_1, \ldots, x_n, \hat{y}_1, \ldots, \hat{y}_n) \neq (x_1, \ldots, x_n, y_1, \ldots, y_n)$, for some i $S_i \ni (x_i, y_i) \neq (x_i, \hat{y}_i) \in S_i$ holds. However, this contradicts that S_i is a function. Q.E.D.

Proposition 2

Suppose $\mathcal{D}(S) = \mathcal{D}(S_1) \times \cdots \times \mathcal{D}(S_n)$. Then, $S_1, \ldots, S_n$ are mutually dependent if and only if there exist sets $U_1, \ldots, U_n$ and functions

$$P_1 : M_1 \times U_1 \longrightarrow Y_1$$
$$\vdots$$
$$P_n : M_n \times U_n \longrightarrow Y_n$$

and

$$k_1 : M \times Y \longrightarrow U_1$$
$$\vdots$$
$$k_n : M \times Y \longrightarrow U_n$$

such that the following hold.

(i) $(m_i, y_i) \in S_i \longleftrightarrow (\exists u_i)(y_i = P_i(m_i, u_i))$

(ii) $(m_1, \ldots, m_n, y_1, \ldots, y_n) \in S \leftrightarrow (\exists (u_1, \ldots, u_n))(\forall i)(y_i = P_i(m_i, u_i)$
$\& \ u_i = K_i(m, y))$

Proof : Suppose $S_1, \ldots, S_n$ are mutually dependent then proposition 1 implies that every subprocess is not functional. Let $S_1, \ldots, S_k$ be not functional while the others are functional

Since S is a function, we can define a function $\hat{P}_i : M \rightarrow Y_i$ as

$$\hat{P}_i(m) = y_i \text{ for every } i \longleftrightarrow S(m) = (\hat{P}_1(m), \ldots, \hat{P}_n(m))$$

Let $U_i = M_1 \times \cdots \times M_{i-1} \times M_{i+1} \times \cdots \times M_n$

Let $K_i(m, y) = (m_1, \ldots, m_{i-1}, m_{i+1}, \ldots, m_n)$

Let $P_i(m_i, u_i) = \hat{P}_i(m_1, \ldots, m_{i-1}, m_i, m_{i+1}, \ldots, m_n)$

Where $u_i = (m_1, \ldots, m_{i-1}, m_{i+1}, \ldots, m_n)$

Since

$$(m_i, y_i) \in S_i \longleftrightarrow (\exists (m_1, \ldots, m_{i-1}, m_{i+1}, \ldots, m_n))(\exists (y_1, \ldots, y_{i-1}, y_{i+1}, \ldots, y_n))((m_1, \ldots, m_n, y_1, \ldots, y_n) \in S)$$

Condition (i) and (ii) hold. Furthermore, since S_1 is not functional $P_1(m_1, u_1)$ depends on u_1. Conversely, suppose $S_1, \ldots, S_n$ are mutually independent. Then it follows from Proposition 1 that $S_1, \ldots, S_n$ are functions that is, $P_i(m_i, u_i) = S_i(m_i)$ for every m_i and u_i. Q.E.D.

The set U_i in Proposition 2 is a representation of interaction and the proposition implies that the existence of interaction means mutual dependency of subprocesses. The interaction introduced by proposition 2 will be referred to as process interaction. The intractions of the processes by Eq. (4) and (5) are examples of process interaction.

Proposition 3

Suppose $S_1, \ldots, S_n$ are functions. Then $S_1, \ldots, S_n$ are mutually dependent if and only if $\mathcal{D}(S)$ is a proper subset of $\mathcal{D}(S_1) \times \cdots \times \mathcal{D}(S_n)$.

The above proposition is a easy result of proposition 1.

However, it is of conceptual significance, that is, it implies existence of another kind of interaction different from process interaction. Let us consider the following example .

$$y_1 = m_1 \tag{13}$$

$$y_2 = 2m_2 \tag{14}$$

$$m_1 + m_2 \leq 10 \tag{15}$$

Where m_1, m_2, y_1, and y_2 are real numbers. The subprocesses given by Eq. (13) and (14) do not have any process interaction but Rel. (15) implies that the subprocesses cannot be independent each other. This is also ascertained by Proposition 3, because $\mathcal{D}(S) = \{(m_1, m_2) | m_1 + m_2 \leq 10\}$ is a proper subset of $\mathcal{D}(S_1) \times \mathcal{D}(S_2) = R \times R$ and S_1 and S_2 are functions. Although this mutual dependency cannot be exprened by an interaction variable directly, we refer to this interaction as system interaction.

4. Coordination Principles for System Interaction

One of the most important problems of a complex system consisting of goal seeking subsystems is the coordination of the subsystems. Before discussing coordination principles for system interaction, we present the concept of coordination briefly. The following presentation follows to Reference (1).

A complex system is itself a goal seeking system which is called overall system denoted by (P, G, D). The family of the subsystems $\{(P_i, G_i, D_i) \mid i = 1, \ldots, n\}$ will be referred to as lower (or first) level. When a coodination scheme is considered a subsystem of the lower level should include a coordination variable and the objective function G_i is formally expressed by

$$G_i : M_i \times Y_i \times B_i \longrightarrow R$$

where B_i is the set of coordinations and will be referred to as goal coordination. The coordinator is also a goal seeking systems, which is denoted by (P_0, G_0, D_0). The goal of the coordinator may not represent the overall goal directly. He can have his own goal different from the overall, but his goal should be compatible with the overall goal. This is the goal harmony of multilevel systems and is represented by (1):
Realization of the coordinator's goal implies realization of the overall goal, or symbolically,

$$D_0(G_0) \longrightarrow D(G)$$

where $D_0(G_0)$ and $D(G)$ are symbolic representations of realization of the coordinator's goal and the overall goal, respectively. When the goal harmony is satisfied, the coordinator has only to seek his goal by manipulating the coordination variable while the lower level subsystems make decisions independently to achieve their goals under the given value of coordination. The goal coordination is one type of coordination and there are other types of it, for instance, process coordination (1).

In general we will denote the set of coordination variable by C and a decision made by the lower level subsystems under the coordination value $\gamma \in C$ by $\hat{m}(\gamma) = (\hat{m}_1(\gamma), \ldots, \hat{m}_n(\gamma))$

In many cases the overall goal G is specified from the beginning and the goals G_i of subsystems can be more or less explicitly understood from G but the goal G_0 of the coordinator cannot be determined by the model of a complex system mentioned so far. In order to specify G_0 we usually introduce a coordination principle. A coordination principle is a principle based on which the coordinator manipulates his cooordination variable. In this paper a coordination principle is represented as a characterization of $D_0(G_0)$.

The necessity of coordination comes from existence of interactions among subprocesses. If a complex system is just an ensemble of mutually independent subsystems, it is not necessary to treat it as a complex system at all. It is, hence, natural that each type of interaction should have its own coordination principle. In Reference (1) coordination principles have been investigated for process interaction. In this section coordination principles for a system only with system interaction will be discussed.

Let

$$\pi_i : M \to M_i \quad (i = 1, \ldots, n)$$

be an algebraic projection such that

$$\pi_i(m_1, m_2, \ldots, m_n) = m_i$$

A subset $M' \subset M$ is called cartesian set if

$$M' = \pi_1(M') \times \cdots \times \pi_n(M')$$

holds. A singleton set $\{m\} \subset M$ is a trivial but important cartesian set. Every subset M' of $M_1 \times \cdots \times M_n$ can be represented by a union of cartesian sets, i.e.,

$$M' = \bigcup_{\varepsilon \in E} M^{\varepsilon}$$

where $M^{\varepsilon} \subset M$ is a cartesian set while $E \ni \varepsilon$ is a suitable index set, because E and M^{ε} can be always defined as

$$E = M$$

and $$M^{\varepsilon} = \{\varepsilon\}$$

As mentioned in Section 3, a system interaction usually does not have an explicit expression. Therefore, it is defficult to treat a system interaction directly by identifying it as usually done for a process interaction. A scheme, then, should be devised to treat the interaction without its explicit expression. The following two coordination principles for a system interaction are based on the fact that every set M can be decompered into a union of cartesion set. If a set of manipulating variables is a cartesian set, clearly there is no system interaction. Therefore, if the coordinator selects a suitable cartesian subset M^{ε} of M as a permissible set, the complex system is resolved into a system of independent subsystems which can achieve the overall solution of the original complex system. In this scheme the most difficult problem is how the coordinator can find a suitable cartesian subset. This can be done by using the sensitivity of the overall goal with respect to variation on E.

Suppose E is a subset of a real vector space. Let $\hat{m}(\varepsilon)$ be the decision made by the lower level subsystems when the permissible set is $M^{\varepsilon} \subset M$. For each $\varepsilon \in E$ let

$$\lambda(\varepsilon) : E \longrightarrow R$$

be an expression of the sensitivity such that $\lambda(\varepsilon)\delta\varepsilon$ is the first order approximation of $g(\hat{m}(\varepsilon+\delta\varepsilon)) - g(\hat{m}(\varepsilon))$ where $g(m) = G(m, P(m))$. Then

Feasible Coordination Principle for System Interaction

$$D_0(G_0) \longleftrightarrow \lambda(\varepsilon)\delta\varepsilon \leq 0$$

where ε is a coordination variable and $\varepsilon \in E$ and $\varepsilon + \delta\varepsilon \in E$ and $g(m)$ represents a profit. The above principle seems trivial. However, many of hierarchical systems are coordinated for system interaction by the above principle (4). In those cases usually the sensitivity $\lambda(\varepsilon)$ is determined by the lower level rather than the coordinator. Let us consider the following simple example of a resource allocation problem. Let

$$y_i = P_i(m_i) \qquad (i = 1, \cdot\cdot, n)$$

where $m_i \in R$ and $y_i \in R$ are reals. The overall goal (profit) is assumed given by

$$g(m) = y_1 + \cdots + y_n$$

where there is the following resource constraint

$$m_1 + \cdots + m_n \leq r \qquad \text{and} \qquad m_i \geq 0$$

Then,

$$M = \{(m_1, \ldots, m_n) \mid m_1 + \cdots + m_n \leq r \ \& \ 0 \leq m_i\}$$

Let $E \subset R^n$ be such that

$$\varepsilon = (\varepsilon_1, \dots, \varepsilon_n) \longleftrightarrow \varepsilon_1 + \dots + \varepsilon_n = r \quad \text{and } \varepsilon_i \geq 0 \quad \text{for}$$

every i . Let

$$M^\varepsilon = \{(m_1, \dots, m_n) \mid 0 \leq m_i \leq \varepsilon_i \text{ for every } i\}$$

M^ε is a cartesian set and $M = \bigcup_{\varepsilon \in E} M^\varepsilon$ where E is a subset of real vector space R^n . Suppose P_i is a monotonously increasing function. Then, $\lambda(\varepsilon)$ is given by

$$\lambda(\varepsilon) = \left(\left(\frac{dP_1}{dm_1}\right)_{\varepsilon_1}, \dots, \left(\frac{dP_n}{dm_n}\right)_{\varepsilon_n}\right)$$

Since $\varepsilon \in E$ and $\varepsilon + \delta\varepsilon \in E$, we have that $\delta\varepsilon = 0$ and $\delta\varepsilon_i = 0$ for $\varepsilon_i = 0$

Consequently

$$\sum_i \left(\frac{dP_i}{dm_i}\right)_{\varepsilon_i} \delta\varepsilon_i \leq 0 \longleftrightarrow \left(\frac{dP_{i_1}}{dm_{i_1}}\right) = \dots = \left(\frac{dP_{i_k}}{dm_{i_k}}\right) \qquad (16)$$

where $\varepsilon_{i_1} \neq 0, \dots, \varepsilon_{i_k} \neq 0$.

In the resource allocation problem the usual coordination procedure is the following

(i) The coordinator allocates the resource tentatively, that is, the permissible set for the manipulating variables is $(0, \varepsilon_1) \times \dots \times (0, \varepsilon_n)$.

(ii) The lower level selects a value $\hat{m}(\varepsilon) = (\hat{m}_1(\varepsilon), \dots, \hat{m}_n(\varepsilon))$ and determines the sensitivity $\lambda(\varepsilon) = \left(\left(\frac{dP_1}{dm_1}\right)_{\varepsilon_1}, \dots, \left(\frac{dP_n}{dm_n}\right)_{\varepsilon_n}\right)$ and reports $\lambda(\varepsilon)$ to the coordinator.

(iii) The coordinator adjusts ε such that the relation (16) is realized.

What is characteristic of the above procedure is that the constraint is always satisfied by $\hat{m}(\varepsilon)$, that is, $\hat{m}(\varepsilon) \in M$ while the following scheme does not satisfy this condition.

Suppose $\bar{M} = \{M_\alpha \mid \alpha \in I \ \& \ M_\alpha \subset M_1 \times \cdots \times M_n\}$ is a family of subsets of $M_1 \times \cdots \times M_n$ such that for some $\alpha \in I$ $M_\alpha = M$ holds. $\bar{M}$ is called a parameterization of M. In the above allocation problem if M_α is defined by

$$M_\alpha = \{(m_1, \ldots, m_n) \mid m_1 + \cdots + m_n \leq \alpha \ \& \ m_i \geq 0\}$$

where $\alpha \in I = R^+$ (the set of non-negative real numbers) $\bar{M}$ is a parameterization of M. Let

$$M_\alpha = \bigcup_{\varepsilon \in E_\alpha} M_\alpha^\varepsilon$$

where M_α^ε is a cartesian set and E_α is assumed a subset of E.

For each E_α let

$$\lambda(\varepsilon, \alpha) : E_\alpha \longrightarrow R$$

be an expression of the sensitivity. Suppose the set of coordination C satisfies the condition

$$(\forall \gamma)(\exists \alpha)(\exists \varepsilon)(\gamma \in C \rightarrow \hat{m}(\gamma) \in M_\alpha^\varepsilon \ \& \ \lambda(\varepsilon, \alpha)\delta\varepsilon \leq 0)$$

Then

<u>Infeasible Coordination Principle for System Interaction</u>

$$D_0(G_1) \longleftrightarrow \hat{m}(\gamma) \in M$$

The present principle is used for coordination of power stations. Let us apply the principle to the previous resource allocation problem. In order to simplify the argument we assume that the constraint is

$$m_1 + \cdots + m_n = r$$

Then

$$M = \{(m_1, \ldots, m_n) \mid m_1 + \cdots + m_n = r \ \& \ m_i \geq 0\}$$

and $M^\varepsilon = \{\varepsilon\}$ where $E = M$.

Let $C = R$ such that

$$G_i(m_i, \gamma) = P_i(m_i) - \gamma m_i$$

In other words γ is the unit cost of the resource. Let

$$M_\alpha = \{(m_1, \dots, m_n) \mid m_1 + \dots + m_n = \alpha \;\&\; m_i \geq 0\}$$

and $M_\alpha^\varepsilon = \{\varepsilon\}$ and

$$\lambda(\varepsilon, \alpha) = \left(\left(\frac{dP_1}{dm_1}\right)_{\varepsilon_1}, \dots, \left(\frac{dP_n}{dm_n}\right)_{\varepsilon_n} \right)$$

Then $\overline{M} = \{M_\alpha \mid \alpha \in R\}$ is a parameterization of M. Furthermore if $\alpha = \hat{m}_1(\gamma) + \dots + \hat{m}_n(\gamma)$, then $\hat{m}(\gamma) \in M_\alpha^\varepsilon$ where $\varepsilon \in \hat{m}(\gamma)$ and $\lambda(\varepsilon, \alpha)\,\delta\varepsilon \leq 0$ holds. It is easy to show that if $\hat{m}(\gamma) \in M$, then $\hat{m}(\gamma)$ is an overall optimal decision under the usual condition of g.

5. Conclusion

In this paper we tried to treat a complex system in an axiomatic way. First we formulated a complex system as a relation on subsystems and showed that the concept of interaction is not a primary concept in the framework of the formulation. As a natural consequence of the formulation two basic type of interaction, process interaction and system interaction, were introduced. Then coordination principles for system interaction were considered. Usually a system interaction cannot be expressed by an explicit variable and so cannot be dealt with directly as a process interaction can be. In order to overcome this difficulty a sensitivity concept was introduced and two coordination principles were proposed based in it.

Most of the results presented in this paper are not deep. However, this is a preliminary trial for the belief that at the present system theoretic considerations are more necessary to advance understanding of complex large scale systems than practically oriented considerations.

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VI.9. STATISTICAL ANALYSIS AND ERROR PROPAGATION IN THE WORLD ECONOMIC MODEL

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Contents

1.0 Introduction and Commentary:

It is the goal of the world modelling project to develop a computer-based dynamical model of the various interactions of the world's social groups and to use this model to predict future patterns of development arising from alternate policy decisions. That is, in its final form the world model is intended as an aid to policy design which will forecast the effects of contemporary decisions over a wide range of human activity and on a global scale. A key aspect of this program is the assumption that the model will give a reasonably accurate forecast of the actual world dynamics over an extended time horizon. Such accuracy is necessary to enhance the relevance of the associated long range planning.

In this regard, certain simplifying aspects in the model construction, such as linearization and the identification of model parameters from restricted or inadequate data, must be examined critically. In particular, it is essential to assess the asymptotic effects of modelling simplifications and/or errors as a measure of the accuracy of long range predictions based on the model. It is the purpose of this paper to record some preliminary studies of some aspects of the problem of modelling errors. Attention is focused on but one portion of the existing world model - the economic submodel.

A detailed description of the model which we examine here together with the basic assumptions which guide our study are given in section 1.1 below. A brief description of the source of the analytical techniques which we use is given in section 1.2. Finally, in section 1.3 we present a summary of some numerical analysis of the errors due to inaccuracies in the parameter identification methods and the structural assumptions of the trade balancing mechanism.

Section 2 which follows contains our analytical study of the parametric modelling errors and section 3 contains our analysis of the trade balancing mechanism.

1.1 The Macro - Economic Model: Basic Assumptions:

The portion of the world model designed to account for the evolution of the regional economies consists of two basic mechanisms. The first is a macro-economic model of each regional economy intended to simulate the historical economic data available for that region and by extrapolation to provide estimates of the economic future of the region. The second mechanism provides for coupling among the regions by modelling the dynamics of world trade and currency exchange. In this section we discuss these two mechanisms and the problems of identifying their functional form from available data.

A. Regional Economic Model: Internal Dynamics:

The basic variables of the macro-economic models of each region are (at year t normalized, t = 0, 1, 2, ...)

$Y(t)$ = gross regional product
$K(t)$ = capital stock
$I(t)$ = investment
$C(t)$ = regional private consumption
$G(t)$ = goverment expenditure
$X(t)$ = regional exports
$M(t)$ = regional imports

Defined by the parameters $\gamma^i(t)$, $Q(t)$, δ, the basic dynamics of the regional economy are contained in the difference equation

(1) $$K(t+1) = (1-\delta)K(t) + [\gamma^i(t)/Q(t)]K(t); \; K(0) = K_0$$
$$t = 0, 1, 2, \ldots$$

Here $Q(t)$ is the capital stock ratio, δ is the depreciation rate for capital, and $\gamma^i(t)$ is the investment ratio. The other variables are related to $K(t)$ via

$$(2) \qquad Y(t) = K(t)/Q(t)$$
$$(3) \qquad I(t) = \gamma^i(t)Y(t)$$
$$(4) \qquad C(t) = \gamma^c(t)Y(t)$$
$$(5) \qquad G(t) = \gamma^g(t)Y(t)$$
$$(6) \qquad X(t) = \gamma^x(t)Y(t)$$
$$(7) \qquad M(t) = \gamma^m(t)Y(t)$$

In addition the regional economy is assumed balanced by

$$(8) \qquad Y(t) = I(t) + C(t) + G(t) + X(t) - M(t)$$

Under the simplifying assumption that the regions to not interact, the parameters $(\delta, Q, \gamma^i, \gamma^c, \gamma^g, \gamma^x, \gamma^m, K_0)$ are determined by matching as closely as possible the trajectories computed by (1 - 8) with actual historical data.

The basic assumptions of this macro - model which show up explicitly in the form of the equations (1 - 8) are

(i) On a macro - scale the historical trends may be well approximated by linear difference and algebraic equations with first order dynamics; i.e., the next value $K(t + 1)$ depends only on the present value $K(t)$, and not on earlier values.

(ii) The model is deterministic and causal. That is, there are no essentially unknown (random) exogenous driving forces or disturbances. Moreover, predictions of future economic states are not considered in computing evolution of the variables.

(iii) The regional economy modelled by (1 - 8) is operating near an equilibrium (of steady growth, perhaps). That is, major disturbances such as market collapse, etc., are not considered.

(iv) The model is "robust enough" to represent vastly differing regions such as heavily developed North America and scarcely developed Southeast Asia. There exist adequate historical data to identify the parameters in this particular functional form and the model is robust enough to provide reasonably accurate descriptions of the various regions under relatively wide ranges of uncertainty in the data.

(v) Implicitly, this model is compatible with the other sectors of the world model in structural form and faithfulness to reality.

To adequately respond to point (v) the economic model must function adequately over relatively long time horizons (t = 50 years) which characterize the time constants of the other subsystems (particularly the population equations) of the world model. We note that these time horizons are roughly twice the length of the time scale (about 25 years) of the available data. For this reason analysis of the growth of errors in the "free" (non-coupled) evolution of the regional model is important. A portion of this analysis is presented in section 2 below.

Related to the assumptions (i - v) above are several possible sources of errors in the computed state trajectories. These include

(i) Over-simplification of the actual dynamics by the assumption of linear, first order dynamics.

(ii) Errors in the available data records for identification of the model (1 - 8).

(iii). Parameter identification errors; that is, errors remaining after the regression techniques have fitted the simulated historical trajectories to the actual ones to determine the parameters.

Although error sources (i) and (ii) are probably more important than (iii) we focus attention here (sec. 2) on (iii) for several reasons. First, the assumption of linear, first order dynamics is to some extent necessitated by the tremendous complexity of the overall modelling effort. If every subsystem (on this level) was modelled by a much more complex form the resulting computational load in the simulation experiments would become unbearable. This basic structural form is compatible with existing models of economies [2, 3, 4], which have proven to be accurate representations of reality, though on a narrower scale. Finally, it would probably be very difficult to identify and compare much more sophisticated structural forms; essentially, the necessary theoretical apparatus is absent.

The undoubted errors (ii) in the historical data are not studied because it is difficult to appraise their magnitudes which vary widely in character from region to region, and because there is little that can be done about them. The reconstruction of the necessary data has formidable prospects. The potentially enormous effects of inadequacies in the data base are not denied. Indeed one outgrowth of this world modelling effort is the recognition of the need for more detailed, accurate data records, comparable across international boundaries.

B. Regional Economic Interaction via Trade:

The second fundamental mechanism of the macro - economic model is the functional coupling of the regional economies via inter-regional trade. The procedure in the simulation adjusts the state variables in the uncoupled regional models so that the total world imports and exports are balanced. Specifically, if $X_k(t)$ and $M_k(t)$ denote the exports and imports of the k^{th} region, $k = 1, 2, \ldots, 10$, as generated by equations (1 - 7) above, then the total world exports and imports are

$$TWX(t) = \sum_{k=1}^{10} X_k(t)$$

$$TWM(t) = \sum_{k=1}^{10} M_k(t)$$

respectively. Since the regional import figures are generated without regard to the activities of other regions, the total imports and exports may not balance; i.e.,

$$\Delta T(t) = TWM(t) - TWX(t)$$

may be non-zero. The trade balancing mechanism of the model adjusts the regional imports to $\hat{M}_k(t)$ so that $TW\hat{M}(t) = TWX(t)$. It returns to the basic state variables to adjust $C_k(t)$ and $G_k(t)$ to $\tilde{C}_k(t)$, $\tilde{G}_k(t)$ so that the regional balance equation

$$Y_k(t) = I_k(t) + X_k(t) + \tilde{C}_k(t) + \tilde{G}_k(t) - \hat{M}_k(t) \tag{8b}$$

is satisfied. The adjustment procedures are somewhat ad hoc, being designed from computational experience. We study them in detail in section 3 below, remarking here only that the methods introduce a basic nonlinearity into the dynamics.

After the world trade has been balanced a 10 x 10 matrix T(t) is defined, based on historical data and a second, recursive adjustment scheme (see sec. 3.2 below), the elements of which give the fraction $t_{ij}(t)$ of the j^{th} region's imports which come from the i^{th} region, i, j = 1, ..., 10. If $\underline{X}(t)$ and $\underline{\hat{M}}(t)$ denote the 10-vectors with components $X_k(t)$, $\hat{M}_k(t)$, respectively, then

$$\underline{X}(t) = T(t)\underline{\hat{M}}(t)$$

While the trade matrix does not affect the basic dynamic of equations (1 - 7) above, or the trade balancing function, it does provide for, and identify the extent of regional economic interaction. As it is evident that the monitoring of this regional interaction is a vital consideration in the future prospects of the global economy, attention must be devoted to the analysis of the effects of modelling errors and structural assumptions on this important variable. Some aspects of this analysis is presented in section 3.2 below.

C. Identification and Structural Errors

As remarked earlier we will focus our attention in these pages on two sources of errors, those generated by residual errors in the parameter identification algorithms and those arising from the trade balance mechanism and the trade matrix construction. The former arise from various regression techniques applied to fit the simulated state trajectories to historical data. These are naturally characterized by their statistical mean and variance parameters which are by - products of the regression procedure. These in turn may be combined with elementary techniques from the theory of stochastic dynamical systems to yield estimates for the mean and variance parameters of the state variables (K(t), Y(t), etc.). We occasionally refer to errors in the state trajectories generated in this way as parametric errors. They are a natural outgrowth of regression procedures.

On the other hand the trade balancing mechanism and the trade matrix construction are designed by ad hoc methods not related to considerations of the real world dynamics. We refer to errors generated in this way as structural. They are much more difficult to analyze than the parametric errors because of the nonlinear relationships involved and the entirely artificial nature of the procedures. Nevertheless, we give some preliminary remarks on this source of errors in section 3. These involve essentially considerations of continuity of the functional relationships.

In summary, we consider here only estimates of the second order properties (mean and variance parameters) of the state variables, justifying this limited goal as compatible with the linear dynamics assumed and consistent with the natural error estimates generated by the regression methods.

1.2 Analytical Techniques:

In the selection of the appropriate analytical framework for the study, two aspects of the world modelling program must be considered. First it is the design of the project to develop a model of the world as a dynamical system, that is, as a system whose future states depend not only on present conditions but also on past ones. Secondly, it is the intention of the project to use the model over long time horizons for forecasting future conditions.

These two aspects lead us to choose the methods of dynamical systems theory for the analysis, and in particular, to use techniques for evaluating the asymptotic properties of such systems.

A. Analysis of the Model as a Dynamical System:

From equations (1 - 7) of the last section it is apparent that the unbalanced equations may be represented by

(1) $$K_k(t + 1) = A_k(t)\ K_k(t) \quad ; \quad K_k(0) \text{ given}$$

(2) $$\underline{p}_k(t) \triangleq \begin{bmatrix} Y_k(t) \\ I_k(t) \\ C_k(t) \\ G_k(t) \\ X_k(t) \\ M_k(t) \end{bmatrix} = Q_k^{-1}(t) \begin{bmatrix} 1 \\ \gamma_k^i(t) \\ \gamma_k^c(t) \\ \gamma_k^g(t) \\ \gamma_k^x(t) \\ \gamma_k^m(t) \end{bmatrix} K_k(t) \triangleq \underline{d}_k(t)\ K_k(t)$$

Thus, in the terminology of systems theory the model for region k has one state variable $K_k(t)$ and six output variables as indicated. Using the notation just introduced the solution is

$$K_k(t) = [\prod_{s=0}^{t-1} A_k(s)]K_k(0)$$

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Thus, in the terminology of systems theory the model for region k has one state variable $K_k(t)$ and six output variables as indicated. Using the notation just introduced the solution is

$$K_k(t) = [\prod_{s=0}^{t-1} A_k(s)]K_k(0)$$

(7) $$\sigma^2_{K_k}(t) = E[K_k^2(t)] - \{E[K_k(t)]\}^2$$

(8) $$\Sigma_{\underline{p}_k}(t) = E[\underline{p}_k(t)\underline{p}_k'(t)] - (E[\underline{p}_k(t)])(E[\underline{p}_k(t)])'$$

The trajectories for the mean values give us information on the average change of the state and output. The magnitude of the variance as a function of time gives a measure of the uncertainty in the state trajectory caused by the identification errors.

Explicit expressions for the mean and variance in (3 - 8) are given in section 2 below in terms of the statistical parameters of the elementary parameters (δ, $Q_k(t)$, $\gamma_k^i(t)$, ...). Numerical evaluation of these expressions under certain assumptions on the statistical properties of the parameters are given below for typical values of the identification errors.

B. Analysis of Structural Properties:

As noted earlier the errors introduced into the evaluation of the state - output trajectories generated by the (artificial) trade balancing mechanism, are fundamentally different in character from the parametric errors considered previously. Postponing the details until section 3, we note here that the trade balance mechanism uses a nonlinear function of the uncoupled state-output variables to produce an adjusted state-output so that world trade is balanced and regional expenditures are balanced: Specifically, the trade balance mechanism takes the output vector $\underline{p}(t)$ defined above into an "adjusted" vector

$$\tilde{\underline{p}}_k(t) = [Y_k(t), I_k(t), \tilde{C}_k(t), \tilde{G}_k(t), X_k(t), \tilde{M}_k(t)]'$$

via a nonlinear function, formally,

$$\tilde{p}_k(t) = f[p_k(t)]$$

which effectively couples the variables $\tilde{C}_k(t)$, $\tilde{G}_k(t)$, $\tilde{M}_k(t)$ to all the variables $M_\ell(t)$ for $\ell \neq k = 1, 2, \ldots, 10$. The new vector $\tilde{p}_k(t)$ is the output of the simulation model with trade balanced.

We note that since the basic state variable $K_k(t)$ is not effected by the trade balancing mechanism (i.e., there is no "feedback"), the model of the region which generates $[K_k(t), p_k(t)]$ is self-consistent over time for each $k = 1, \ldots, 10$.

Thus, to ascertain the effects of the trade balance mechanism on error generation, it suffices to perform a static analysis to determine the sensitivity of the map $\tilde{p} = f(p)$ to variations in the functional form of $f(\cdot)$. Mathematically this is a question of continuity. See section 3.1 for the details of the analysis of this point.

1.3 Computational Results:

A. General Remarks:

In this section we summarize briefly some relevant error estimates made using the analysis which follows in sections 2 and 3 and the available data for the economic model. We emphasize that the computations presented here are very preliminary. We have not, for example, analyzed the actual computational routines used in the economic model but only our own simplified versions. Neither have we reviewed the accuracy of the actual historical data which was used to generate the model parameters. Rather we have taken the model and data as presented and estimated the long range effects of errors in identifying the model parameters from that data.

The reasons for these simplifications are twofold. First to do a complete error analysis would require analysis and computational effort comparable with that required to generate the original model trajectories. For example, it is necessary to return to the basic historical data to compute some variance parameters crucial in the error analysis. In the future, of course, it will be possible to routinely include useful calculations such as these as part of the identification procedure and obtain error estimates along with the predicted trajectories.

The second basic reason for restricting attention to some relatively simple computations is simply a lack of time. The present writer joined the project only recently and has had only a comparatively limited time to devote to the work. Error estimates are considered to be a crucial part of the model and their computation recording will be an important part of the effort as it continues.

Before discussing our computations *per se* a few general remarks are in order. First the problem of establishing an accurate data base for a modelling effort of this scope is enormous. Data from different regions of the world may vary widely in availability and accuracy. They are incompatible in units, in manner of recording, and in meaning. For example, gross regional product for different regions may include or exclude various quantities which must in each such case be estimated from different sources and incorporated into the data base. In some countries necessary figures are not even kept, and must be inferred from other figures for the purposes of the model. The accuracy of data collection methods varies widely from country to country as may be imagined.

Secondly, in a model of the size anticipated for the final state of the project, relatively simple relationships must be used to assure that the model will fit on existing, available computers. An excess of extremely complex functional relationships will make the simulation procedures take too long and introduces the possibility of too many machine errors. Moreover, simple functional relationships are probably most appropriate for a data base varying widely in accuracy.

The error analysis itself serves two purposes in the project. First it attaches a confidence level to any predictions made using the model by providing approximate figures for the mean and variance of the variables (gross regional product, government expenditures, etc.) upon which the projections are based. Secondly, it indicates those parameters to which the model is sensitive. Estimation errors in these parameters have a much larger effect than errors in the other parameters. Accordingly, it is worthwhile to expend greater amounts of effort in the identification of the sensitive parameters than in the others. Examples of sensitive and insensitive parameters will be indicated in the computations below.

B. Effects of Parametric Errors:

From section 2.1 below the basic stepping equation for the economic model is

(1) $$K(t+1) = (1-\delta)K(t) + [\gamma^{i}(t)/Q(t)]K(t)$$
$$K(0) = Ko; \quad t = 0, 1, 2, \ldots$$

The gross regional output Y(t) is given by

(2) $$Y(t) = K(t)/Q(t)$$

Since regional economic data are most commonly summarized by the regional output Y(t) instead of the capital stock K(t), it is convenient to convert the basic stepping equation to

(3) $$Y(t+1) = Q^{-1}(t+1)[(1-\delta)Q(t) + \gamma^{i}(t)]Y(t)$$
$$Y(0) = Y_0 \quad ; \quad t = 0, 1, 2, \ldots$$

Thus, the gross regional output from this model depends on four parameters $Q(t)$, $\gamma^{i}(t)$, δ, Y_0. We will see that the model is most sensitive to Q(t), as may be readily deduced from equation (3).

In the analysis of section 2 we assume that the parameters

(Q, γ, δ, Y_0) are random variables with known means and variances which may be computed from the available data.* For a random variable x, let $m_x(t)$, $\sigma_x^2(t)$ denote the mean and variance of x, respectively. Using the techniques of section 2 we compute the mean of the gross regional product to be

(4) $$MY(t+1) = [M_Q^{-1}(t+1) + \sigma_Q^2 M_Q^{-3}(t+1)][(1-\delta)M_Q(t) + M_{\gamma i}(t)]MY(t)$$

$$MY(0) = MY_0 \; ; \quad t = 0, 1, 2, \ldots$$

Here we have taken δ to be a constant for reasons specified below, and made a number of assumptions on the statistical nature of the random processes $(Q(t), \gamma^i(t))$ all recounted and considered in section 2. To compute the variance of Y(t), it is necessary to first compute the second moment, explicitly

(4) $$EY^2(t+1) = [M_Q^{-2}(t+1) + 3\sigma_Q^2 M_Q^{-4}(t+1)]$$

$$\cdot [(1-\delta)^2 (M_Q^2(t) + \sigma_Q^2) + 2(1-\delta)M_Q(t)M_{\gamma i}(t)$$

$$+ M_{\gamma i}{}^2(t) + \sigma_{\gamma i}^2] \cdot EY^2(t)$$

$$EY^2(0) = M_{Y_0}^2 + \sigma_{Y_0}^2$$

We then form

(5) $$\sigma_Y^2(t) = EY^2(t) - M_Y^2(t)$$

* The techniques used to compute these quantities are quite elementary and are summarized with an example in the Appendix.

and compute the standard deviation by taking the square root of the variance.

C. Results for the North American Region:

Using the historical data for the North American Región we compute

(a) Investment ratio $\gamma^i(t)$:

mean $\gamma^i(t) = m_{\gamma i}(t) = .183894 - .000680 \cdot t$

variance $\gamma i = \sigma^2_{\gamma i}(t) = .3506 \times 10^{-4}$

(b) Capital output ratio $Q(t)$:

mean $Q(t) = m_Q(t) = 3.804873 - .044515 \cdot t$

variance $Q(t) = \sigma^2_Q(t) = .01093$

(c) Initial gross regional product Y_0:

mean $Y_0 = m_{Y_0} = 413.305$

variance $Y_0 = \sigma^2_{Y_0} = 41.33$

(d) Capital depreciation δ:

$\delta = .03$

These figures were computed from the original historical data using the procedure outlined in the appendix, with the exception of $\sigma^2_{Y_0}$ which was a "guess" (no data were available for an estimate of this variable).

The capital depreciation rate δ was set at $(35 \text{ years})^{-1} = .03$ in the basic computations. This figure is one of the most difficult to estimate from available data. Essentially, δ is an average of depreciation rates for capital in various forms including structures, business machines, etc., each of which depreciates at a different rate. Accordingly, we selected this nominal value for our analysis, as does the original economic model, and then varied the value over a certain range to investigate the sensitivity of the error estimates to this parameter.

A graph of the mean and standard deviation for the North American region for the values (a - d) is shown in Figure 1. As one can see the error, as measured by the standard deviation grows by about 1% per year, to a figure of (244/1066) x 100% at the end of 25 years (1975). The mean tracks the historical trajectory of the regional output well, as the identification methods were designed with this objective.

In a crude sense the standard deviation provides a measure of the level of confidence we have in the projections of the model. For example, if we were to start the model in operation at the present date, we could expect the uncertainty in our forecasts of the future to increase by about 1% (of the regional product) per year. Figure 2 is a heuristic view of this evolution of uncertainty. The function p(Y, t) denotes the probability density function of Y(t). We take p(·) centered at the mean of Y(t) with a "spread" about the mean proportional to the variance of Y(t).

It is appropriate to note here that the actual stepping equation used in the Economic Model is somewhat more complex than the one we have used here. It includes a mechanism for assuring that the regional balance equation is satisfied. See Kominek [1, p. 95]. This mechanism is such that the modelling errors we have examined here will be somewhat larger than in the present case. Preliminary analysis indicates, however, that this increase will not be substantial compared to the 1% per year figure noted above.

In Figures 3 - 7 we record experiments which attempt to reduce

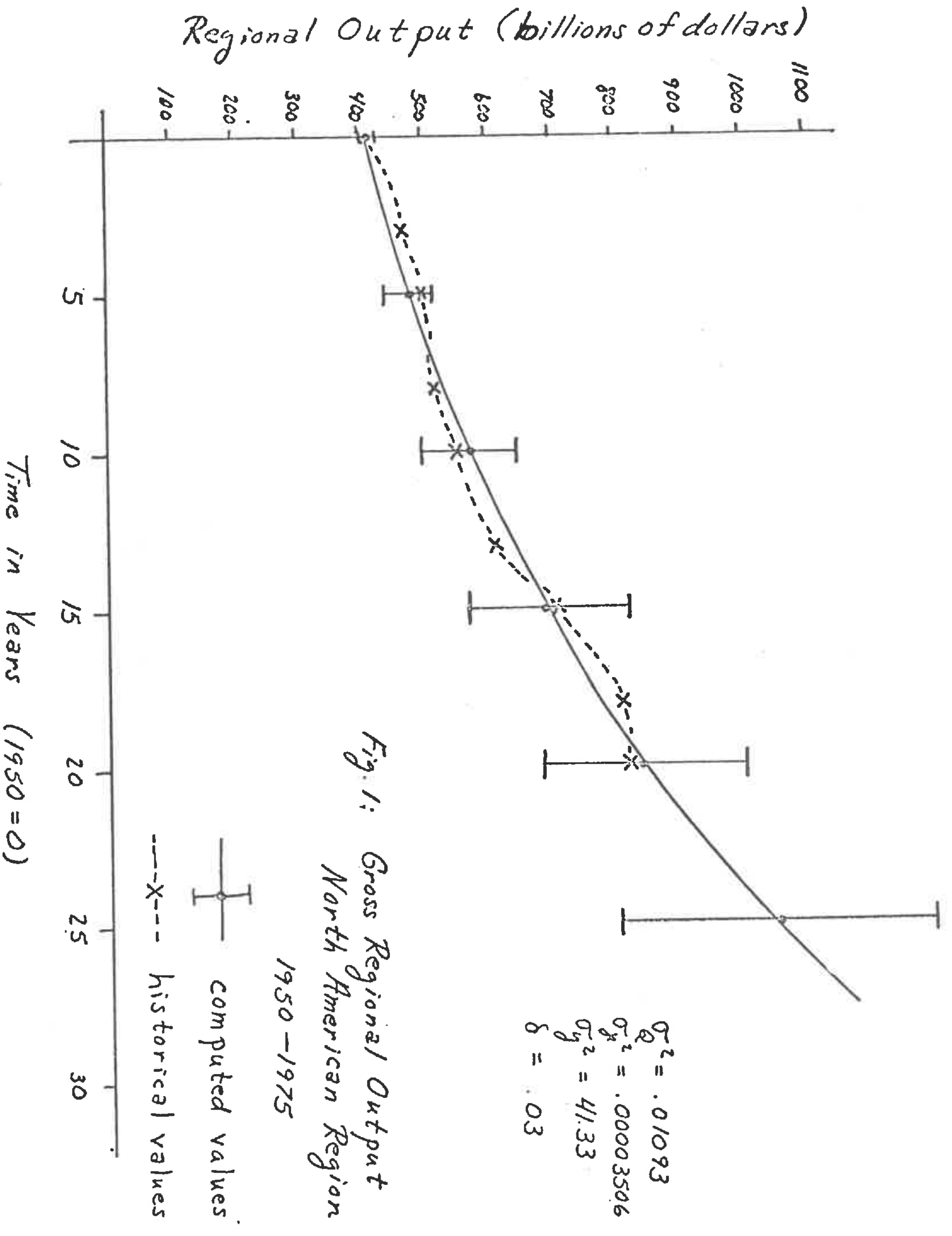

Fig. 1: Gross Regional Output North American Region 1950–1975

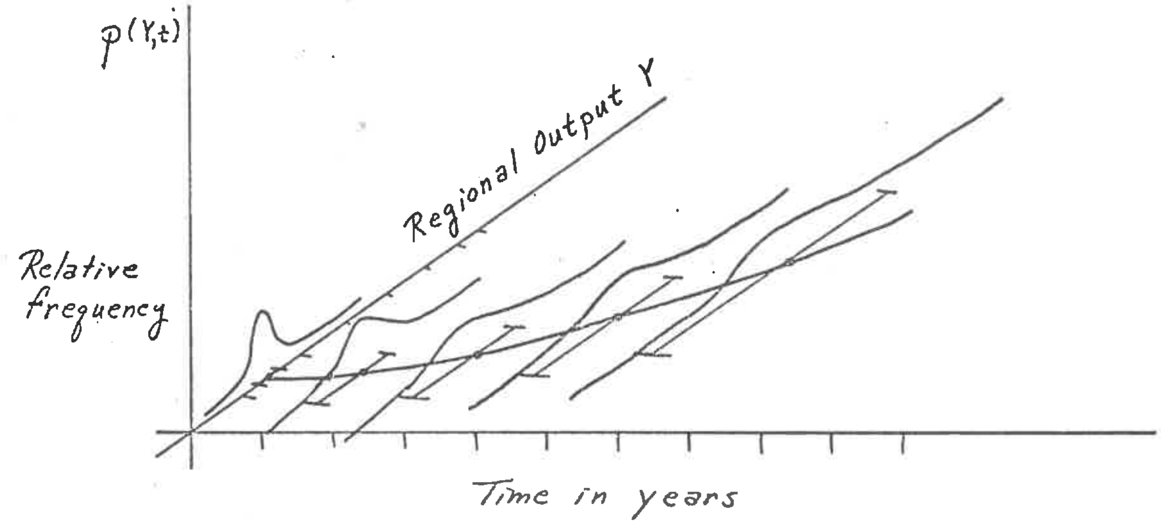

Fig. 2: Heuristic Evolution of Error Probability Distributions

the magnitude of the estimation errors. In Figure 3 the variance of the investment ratio γ^i is reduced by a factor of ten. The effect on the error magnitudes as measured by the standard deviation. The conclusion is that the model is insensitive to this parameter at its present average magnitude.

In Figure 4 we reduce the variance of the initial value of the regional output Y_0 to zero and observe little effect on the error magnitudes. This observation bears out earlier conclusions as a result of attempts to identify Y_0 to cause the regional product to track the historical trajectory. See Kominek [1, p. 18].

In Figure 5 we show the results of reducing the variance of the capital output ratio Q(t) by a factor of ten. Evidently, the model is rather sensitive to variations in this parameter about its nominal value. The error at the twenty - fifth year is reduced from 25% (Figure 1) to about 10% in the present case. Hence, efforts to improve the errors in the forecasts of the economic model should focus on obtaining better estimates of the parameter Q(t).

In Figures 6 and 7 we consider the results of varying the values of the capital depreciation rate δ from 0.02 in Figure 6 to 0.045 in Figure 7. As one can see by comparing these graphs with Figure 1 there is a slight decrease in the error values as δ increases. Note that the trajectory of the mean varies substantially from as δ changes. This would be expected from a glance at the equation. One should not be misled by this particular variation. The real story is in the change of the errors which we judge to be slight, and hence, conclude that the model is relatively insensitive to these variations in δ.

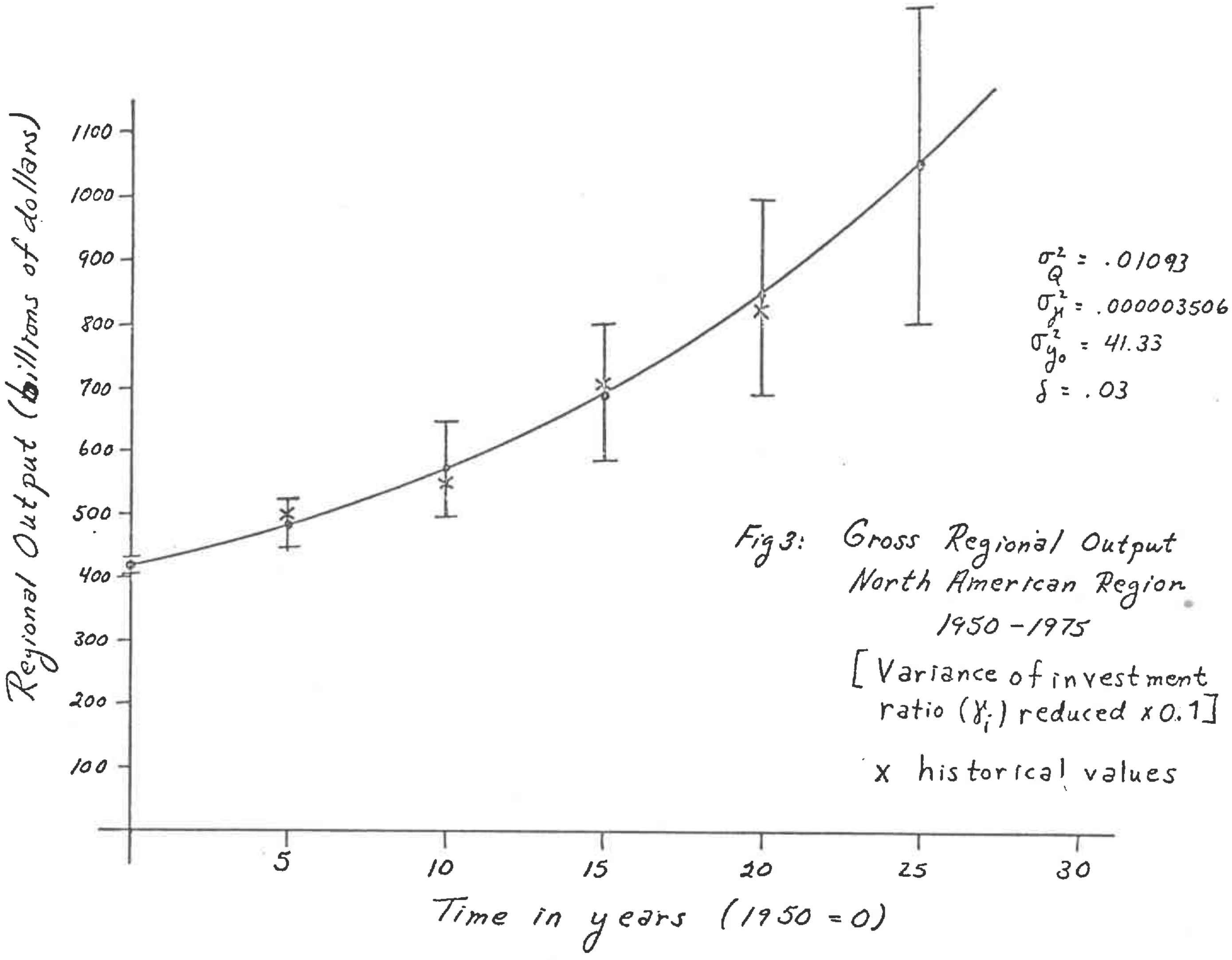

Fig 3: Gross Regional Output North American Region 1950 - 1975 [Variance of investment ratio (γ_i) reduced x 0.1]

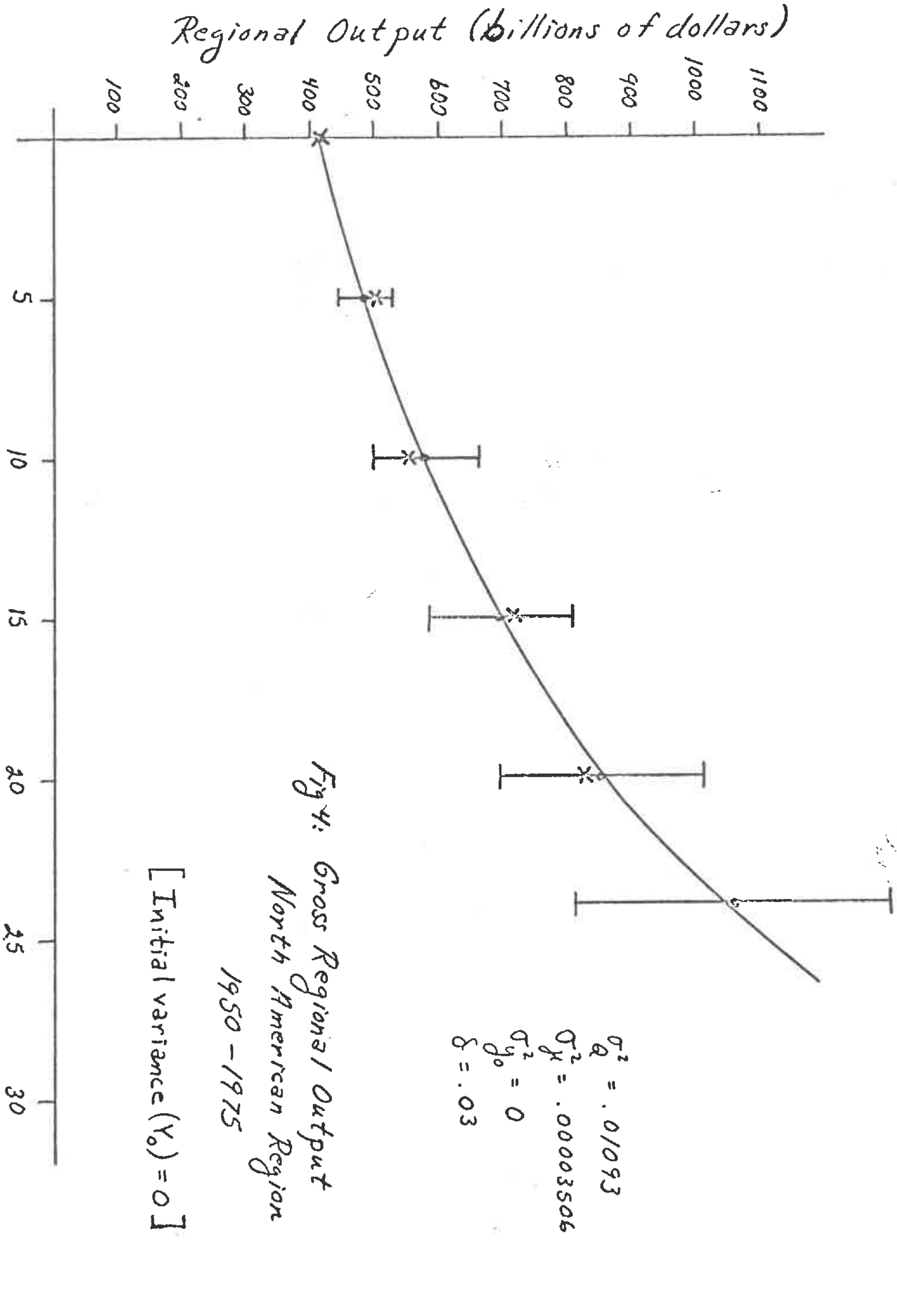

Fig 4. Gross Regional Output North American Region 1950 – 1975 [Initial variance (Y_0) = 0]

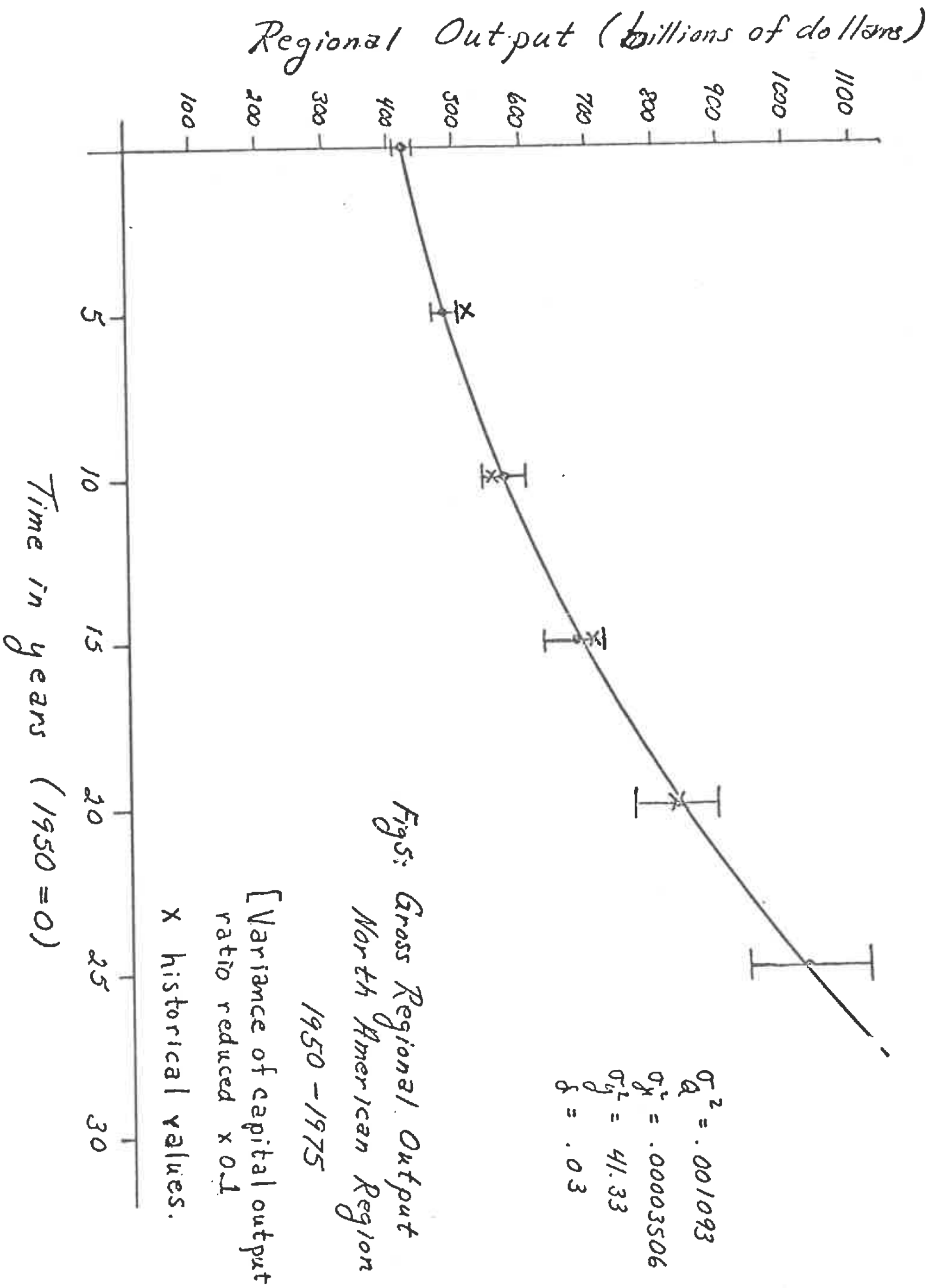

Fig 5: Gross Regional Output
North American Region
1950 – 1975

[Variance of capital output ratio reduced x 0.1

x historical values.

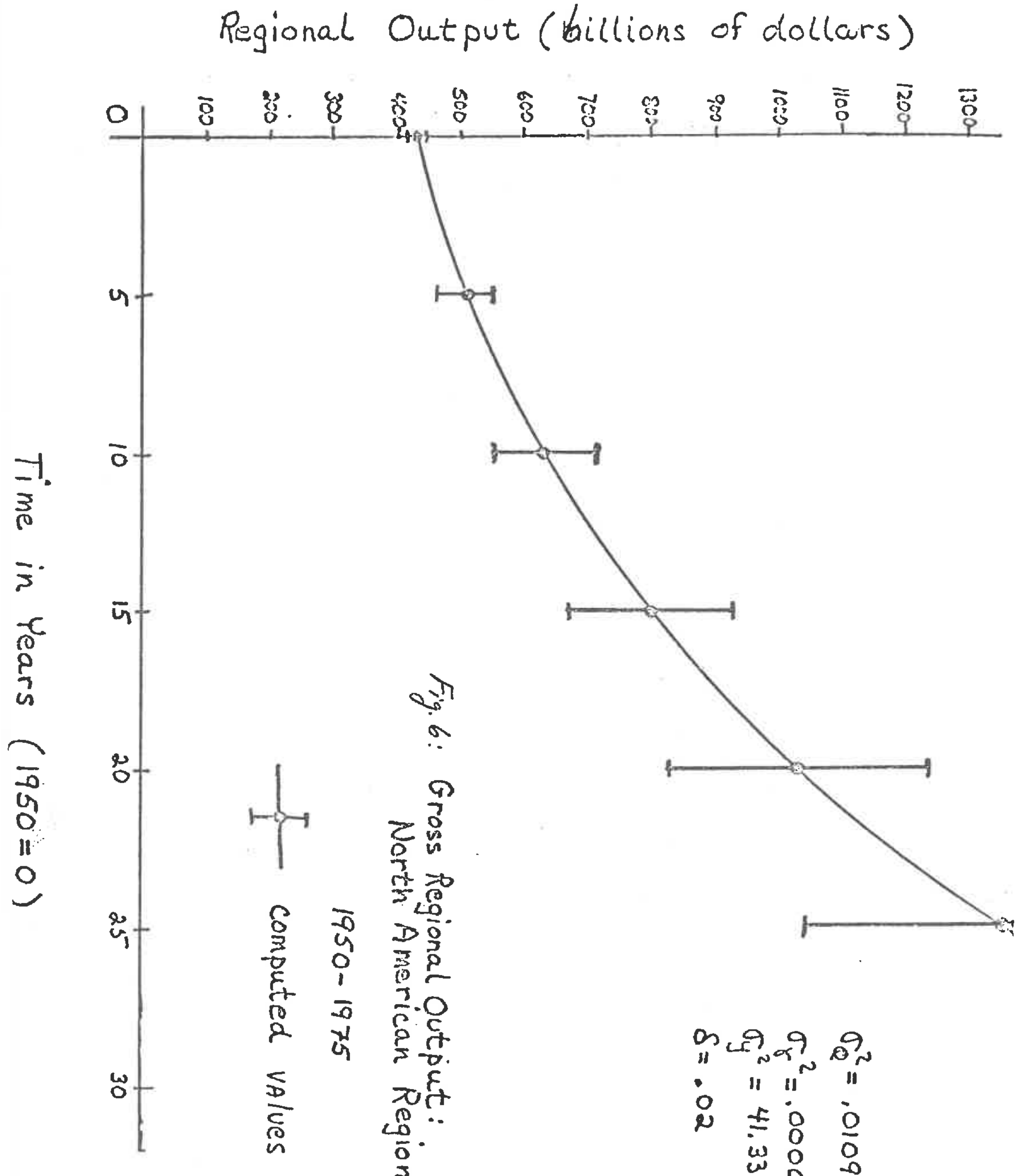

Fig. 6: Gross Regional Output: North American Region 1950-1975

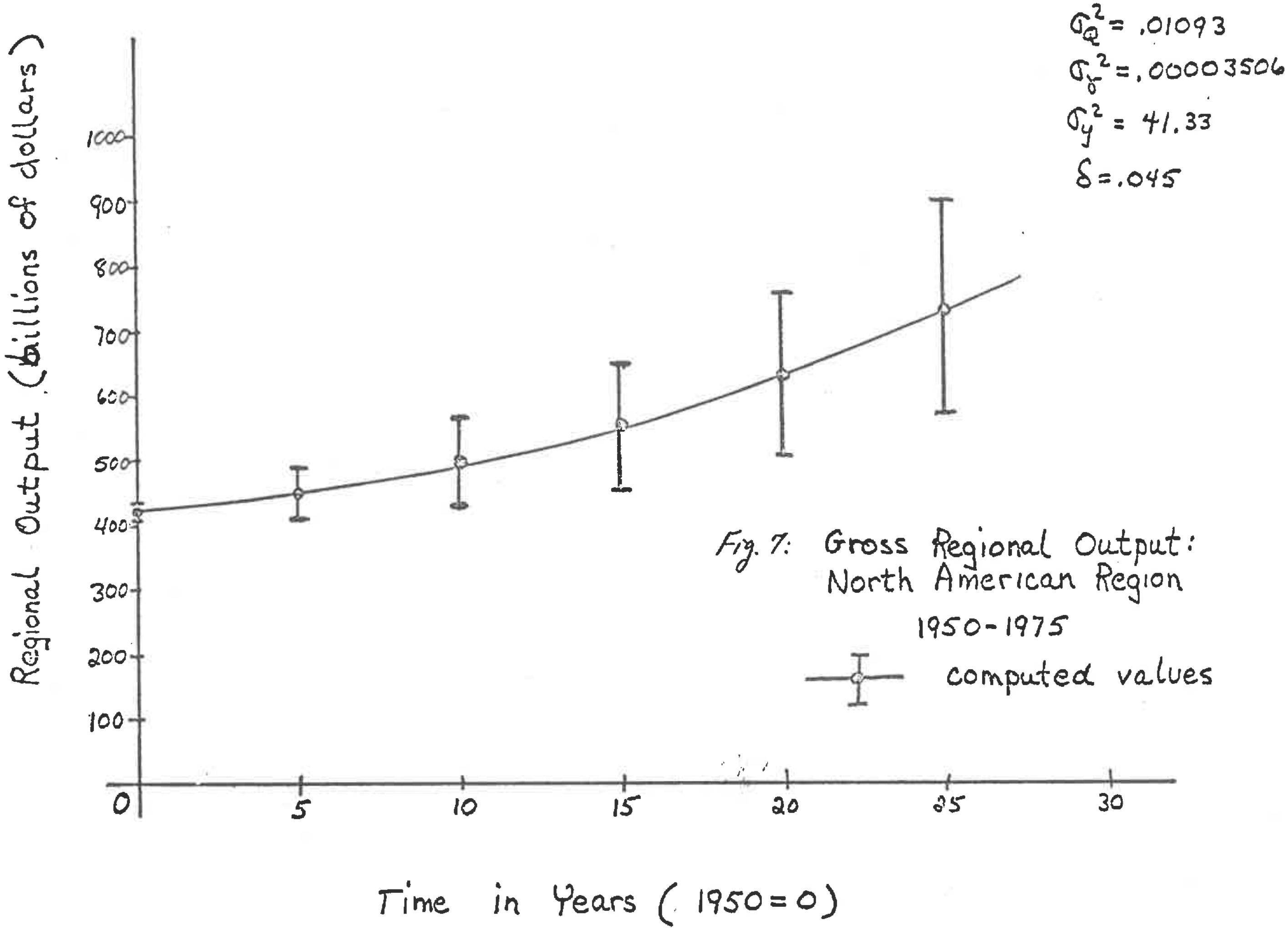

Fig. 7: Gross Regional Output: North American Region 1950-1975

D. Results for the Southeast Asia Region:

In Figure 8 we show the basic error estimates for region 9 (Southeast Asia) of the Economic Model. This compares with Figure 1 for North America. Again we have selected δ = .03 as a rough estimate. Notice that the error for Southeast Asia due to parameter identification errors is about 14% at 25 years, a favorable comparison with the figures for North America. Keep in mind in this comparison that the errors in the data base for each region are not included in the present study. Intuition suggests that if these errors were estimable and incorporated in the analysis, the trajectories for Southeast Asia would show percentage errors comparable with or greater than those of North America.

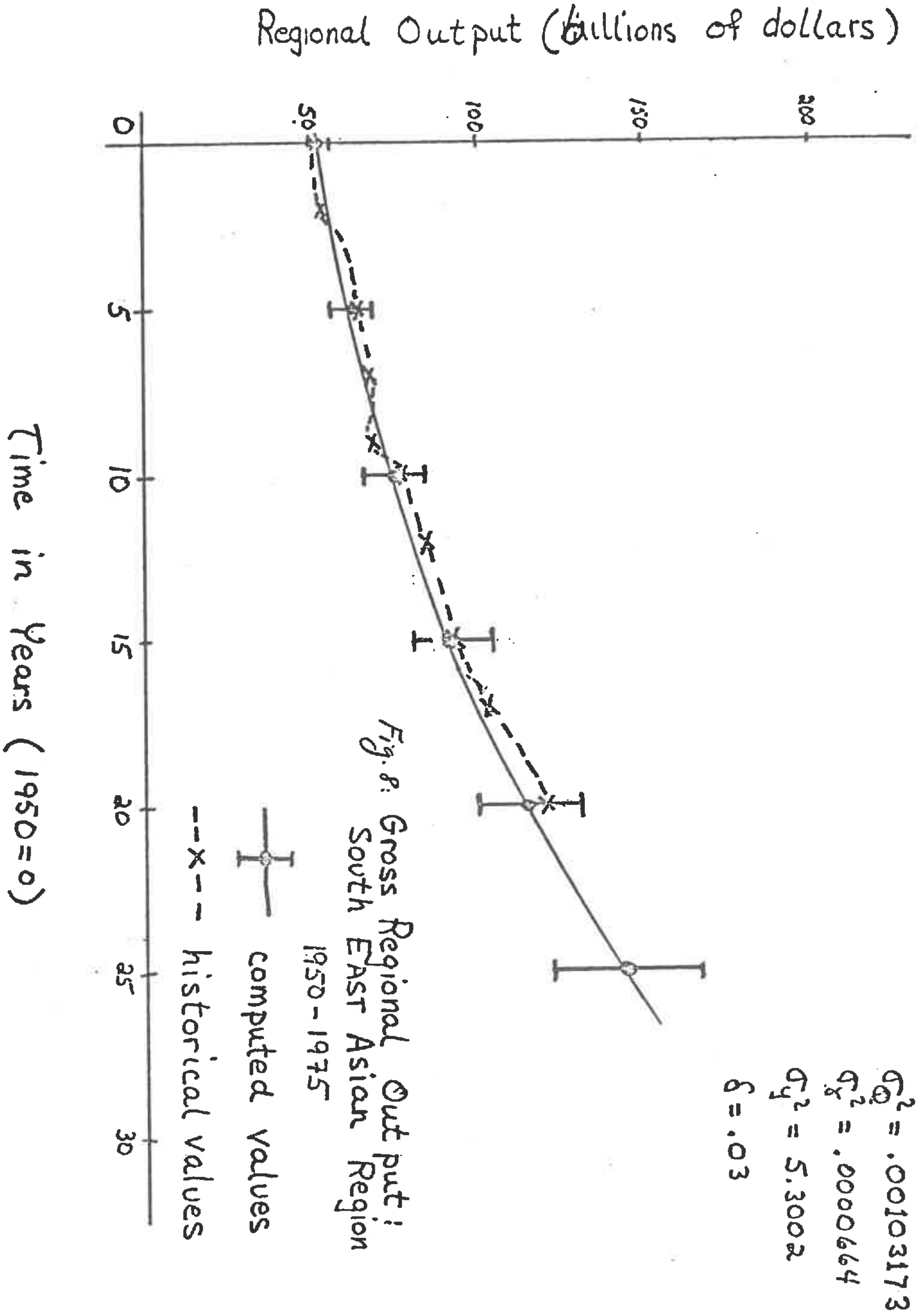

Fig. 8: Gross Regional Output: South EAST Asian Region 1950-1975

2.0 Evolution of Parametric Errors in the Economic Model:

In this section we present the details of the analysis used to generate the computational results of section 1.3. In particular, we set out in an explicit fashion the assumptions used in the analysis in section 2.1. In section 2.2 we compute approximate evolution equations for the modelling errors under two different assumptions on the parameters $[\dot{Q}(t), \gamma^{i}(t)]$ as random processes including the assumption that they are Markov processes. We also consider aspects of the case when the capital depreciation rate $\dot{\delta}$ is a random variable with known mean and variance. Recall from our earlier remarks, these parameters are extremely difficult to estimate; hence, no computational results are given.

2.1 Equations and Statistical Assumptions:

A. State Equation:

From section 1.1 the basic equations of the economic component of the world model for one region are

$$K(t + 1) = (1 - \delta)K(t) + I(t); \quad K(0) = K_0; \; t = 0, 1, 2, \ldots$$

$$(1) \qquad Y(t) = K(t)/Q(t)$$

$$I(t) = \gamma^i(t)Y(t)$$

where $Q(t)$ and $\gamma^i(t)$ are parameters determined from the data available.

In this section, we will give formulas for statistical parameters (mean and variance) of the variables $K(t)$, $Y(t)$, $I(t)$ as generated by the above model.

The parameters δ, $\gamma^i(t)$, $Q(t)$, K_0 for the model are determined essentially by regression techniques which recursively compare the model generated trajectories for $K(t)$, $Y(t)$, $I(t)$ with historical values. While several different techniques have been used to estimate the parameters, each essentially provides a mean value for each parameter and a value for the variance of that estimate. Typical expressions are given in Kominek [1, p. 100]. Thus, in attempting to evaluate the evolution of errors in the model, it is appropriate to assume that only second order statistics are available.

Accordingly, we assume that for each t, $\gamma^i(t)$, $Q(t)$ are random variables whose means and variances are known to us, and we treat δ and K_0 in a similar fashion. The collection $\{\gamma^i(t)\}_{t\geq 0}$ are then random processes, and consequently, $\{K(t), Y(t), I(t)\}_{t\geq 0}$ is a random process whose properties are of interest to us.

We make two distinct assumptions concerning the parameter processes:

(i) $\{\gamma^i(t)\}$, $\{Q(t)\}$ are mutually independent random processes, each composed of independent random variables.

(ii) $\{\gamma^i(t)\}$, $\{Q(t)\}$ are mutu~lly independent Markov processes generated by the equations

$$Q(t+1) = A_1(t)Q(t) + b_1(t)w(t)$$

$$\gamma^i(t+1) = A_2(t)\gamma^i(t) + b_2(t)v(t)$$

where A_i, b_i $i = 1, 2$ are to be determined from the data, and $\{w(t)\}$, $\{v(t)\}$ are sequences of independent, identically distributed random variables.

We will assume further

(iii) δ, K_0 are mutually indpendent random variables, independent of the processes $\{\gamma^i(t), Q(t)\}$.

Remark: Assumption (ii) represents an effort to account for correlation in the values of $\gamma^i(t)$ and $Q(t)$ from year to year in the belief that these parameters are not completely independent of past values. While its form appears rather special, the linear structure is appropriate for realizing the second order statistics available, and is compatible with the general model structure. With assumption (ii) the process $\{K(t), Y(t), I(t), Q(t), \gamma^i(t)\}$ is Markovian and the analytical theory of Markov process may be brought to bear on the problem.

We treat the model under both assumptions (i) and (ii) in section 2.2 below. First, however, we given a precise statement of the problem to be investigated.

B. Problem: Long Term Effects of Modeling Errors:

A key aspect of the world modeling effort is the assumption that the model will give a reasonably accurate forecast of the actual world dynamics over an extended time horizon. Thus, the long range effects of modeling errors must be investigated to assess the probably accuracy of predictions based on the model. By restricting attention to an analysis of the basic economic submodel we can examine in a simple setting one aspect of error propagation that caused by errors in parameter identification.

In this context then, the precise problem at hand is to bound the growth of the mean and variance of $(K(t))$, $Y(t))$, $I(t))$ in terms of the statistical estimates of the parameters $(\gamma^{i}(t), Q(t))$. Or in mathematical terms evaluate

$$m_K(t) = \text{mean } K(t)$$

$$\sigma_K^2(t) = \text{variance of } K(t)$$

as functions of the mean and variance parameters of $(\gamma^{i}(t), Q(t))$, and estimate the magnitude of $m_K(t)$, $\sigma_K^2(t)$ as t becomes large.

2.2 Evolution Equations for Modeling Errors:

In this section we examine the statistical properties of the solutions of equations (1) under the assumptions (i - iii) above, separating the analysis for (i) and (ii). It is convenient to compress (1) to the single difference equation

(2) $$K(t+1) = [(1 - \delta) + \gamma^{i}(t)/Q(t)]\, K(t) \; ; \; K(0) = K_0$$

and to identify the random process

$$A(t) = (1 - \delta) + \gamma^{i}(t)/Q(t)$$

Then the solution of (2.1) has the form

(3) $$K(t) = [\prod_{s=0}^{t-1} A(s)]K_0,$$

and we seek the properties of the product

$$P(t) = \prod_{s=0}^{t} A(s)$$

subject to the enumerated assumptions.

A. Assumption (i): $\{Q_{(t)}\}$, $\{\gamma^{i}_{(t)}\}$ are White Noises:

For a random variable x we adopt the notation

$$E(x) = m_x = \text{mean of } x$$
$$E(x-m_x)^2 = \sigma_x^2 = \text{variance of } x.$$

In this section we assume that $\{\gamma^{i}(t)\}$ and $\{Q(t)\}$ appearing in (2) are independent random processes, composed of mutually independent random variables $Q(t)$, $\gamma^{i}(t)$, with known statistical parameters

$$m_Q(t),\ \sigma_Q^2(t)$$
$$m_\gamma(t),\ \sigma_\gamma^2(t)$$

We assume further that δ, K_0 are mutually independent random variables also independent of $Q(t)$, $\gamma^i(t)$ for each t, with known means and variances $(m_\delta, \sigma_\delta^2)$, $(m_{K_0}, \sigma_{K_0}^2)$ respectively.

Remark: From Kominek [1, p. 100] typical figures for the North American region are

$$m_\gamma(t) = .184 - (.001)t \ ; \ \sigma_\gamma^2(t) = .017$$

$$m_Q(t) = 3.8 - (.045)t \ ; \ \sigma_Q^2(t) = .044$$

$$m_\delta = .03 \ ; \ \sigma_\delta^2 = .003^\dagger$$

From (3) we have

$$E(K(t) = E[\prod_{s=0}^{t-1} A(s)] \cdot E(K_0)$$

as a consequence of the assumptions on K_0, δ, $Q(t)$, $\gamma^i(t)$. Now

$$A(s) = (1 - \delta) + \gamma^i(s)/Q(s)$$

and because δ is random the sequence $\{A(s)\}$ is not composed of independent variables. However, it is of interest to consider the additional assumption.

Case 1: δ is a known constant

Remark: This might be an appropriate assumption, not in the sense that δ is by any means easily determined - on the contrary, it is apparently the most difficult to compute - but in the sense that

† Estimated from $\delta = (35 \text{ years})^{-1}$.

a range of estimates could be evaluated for various values of δ.

This assumption makes $\{A(s)\}$ an independent sequence, using this fact, we have

$$E[K(t)] = \prod_{s=0}^{t-1} E[A(s)] \quad E(K_0)$$

Now

$$E[A(s)] = (1 - \delta) + E[Y(t)] \cdot E(Q^{-1}(t))$$

To evaluate $E(Q^{-1}(t))$ we use the following:

Lemma: Let x be a random variable with mean and variance (m_x, σ_x^2). Let g be a real-valued, twice continuously differentiable function, then

$$E[g(x)] = g(m_x) + \frac{1}{2} \sigma_x^2 \; g'(m_x)$$

and

$$E[g^2(x)] = g^2(m_x) + \sigma_x^2 \{[g'(m_x)]^2 + gg''(m_x)\}$$

So

$$\sigma_g^2(x) \doteq g^2(m_x) + \sigma_x^2\{[g'(m_x)]^2 + gg''(m_x)\}$$

$$-[g(m_x) + \frac{1}{2} \sigma_x^2 \; g''(m_x)]^2$$

Here, g', g'' denote derivatives of g.

Hence

(4) $$E(Q^{-1}(t)) \simeq [m_Q(t)]^{-1} + \sigma_Q^2[m_Q(t)]^{-3}$$

(5) $$E(Q^{-2}(t)) \simeq [m_Q(t)]^{-2} + 3\,\sigma_Q^2\,[m_Q(t)]^{-4}$$

And we compute

(6) $$E[A(s)] \simeq (1-\delta) + m_Y(s)\cdot\{[m_Q(s)]^{-1} + \sigma_Q^2[m_Q(s)]^{-3}\}$$

So it follows that

(7) $$E(K(t)) \simeq [\prod_{s=0}^{t-1} (1-\delta) + m_Y(s)\cdot\{[m_Q(s)]^{-1} + \sigma_Q^2[m_Q(s)]^{-3}\}]\cdot m_{K_0}$$

In a similar fashion we find

(8) $$E(K^2(t)) = \prod_{s=0}^{t-1} E[A^2(s)]\cdot E(K_0^2)$$

$$\simeq [(1-\delta)^2 + 2(1-\delta)m_Y(s)\cdot\{[m_Q(s)]^{-1} + \sigma_Q^2[m_Q(s)]^{-3}\}$$

$$+ [\sigma_Y^2 + m_Y^2(s)]\cdot\{[m_Q(s)]^{-2} + 3\sigma_Q^2\,[m_Q(s)]^{-4}\}]\cdot(\sigma_{K_0}^2 + m_{K_0}^2)$$

And so, the variance

(9) $$\sigma_K^2(t) = E(K^2(t)) - (EK(t))$$

may be expressed in terms of the elementary parameters m_Q, σ_Q^2, m_Y, σ_Y^2, $\sigma_{K_0}^2$, m_{K_0}, and δ.

Case 2: δ is a random variable with m_δ, σ_δ^2 known.

This case involves more approximations and yields more complex formulae than the last. Nevertheless, if statistical evaluations of δ are available it may be advantageous to use this information the error analysis.

For simplicity we define

$$A(s) = (1 - \delta) + \gamma^i(s)/Q(s)$$

$$\triangleq a + b(s)$$

and

(10) $$K(t) = \log K(t) = \sum_{s=0}^{t-1} \log [a + b(s)] + \log (K_0)$$

Hence, with $E(K(t)) = m_k(t)$ we have

(11) $$m_k(t) = E \log (K_0) + \sum_{s=0}^{t-1} E \log [a + b(s)]$$

Now $a + b(s)$ is a random variable with

$$m_{a+b(s)} = m_{(1-\delta)} + m_{\gamma(s)} \cdot E\{Q^{-1}(s)\}$$

$$\sigma^2_{a+b(s)} = \sigma^2_{(1-\delta)} + \sigma^2_{\gamma^i(s)/Q(s)}$$

which may be approximated using our earlier techniques.

Thus,

$$E \log [a+b(s)] \doteq \log[m_{(1-\delta)} + m_{Y(s)} \cdot \{E\, Q(\tilde{s}^{1})\}]$$

$$- \frac{1}{2} \sigma^2_{a+b(s)} \cdot [m_{(1-\delta)} + m_{Y(s)} \cdot E\{Q(\tilde{s}^{1})\}]^{-2}$$

Thus,

$$(12) \quad E \log K_t \doteq E \log K_0 + \sum_{s=0}^{t-1} \log [m_{(1-\delta)} + m_{Y(s)} \cdot E\{Q(\tilde{s}^{1})\}]$$

$$- \frac{1}{2} \sum_{s=0}^{t-1} \sigma^2_{a+b(s)} [m_{(1-\delta)} + m_{Y(s)} \cdot E\{Q(\tilde{s}^{1})\}]^{-2}$$

<u>Lemma</u>: If x is a positive valued random variable then

$$E \log x \doteq \log m_x - \frac{1}{2} \sigma^2_x (m_x^{-2})$$

$$E \log x^2 \doteq (2 \log m_x \div \sigma^2_x m_x^{-2})$$

Hence,

$$(13) \quad \log m_K(t) - \frac{1}{2} \sigma^2_K(t) m_K^{-2}(t) \doteq \log m_K(0) - \frac{1}{2} \sigma^2_{K_0} m_K^{-2}(0)$$

$$+ \sum_{s=0}^{t-1} \log [m_{(1-\delta)} + m_{Y(s)} \cdot E(Q(\tilde{s}^{1})]$$

$$- \sum_{s=0}^{t-1} \sigma^2_{a+b(s)} [m_{(1-\delta)} + m_{Y(s)} \cdot E(Q(\tilde{s}^{1})]^{-2}$$

and a similar expression may be derived for the second moment.

B. Assumption (ii) $\{\gamma^i(s)\}$, $\{Q(s)\}$ Markov Processes:

Suppose that we relax the assumption that $Q(s)$ and $\gamma^i(s)$ are sequences of independent random variables, and assume that $\{Q(s)\}_{s \geq 0}$ and $\{\gamma^i(s)\}_{s \geq 0}$ are sequences with non-degenerate autocorrelation functions

$$E[(Q(t)\ Q(s))] = \Gamma_Q(t, s)\ ;\ t, s \geq 0$$

and similarly for γ^i.

This flexibility would allow for the possibility that the capital output and investment ratios $(Q(t), \gamma^i(t))$ of this year could depend (in a stochastic way) on past years.

Thus, while it may be difficult to get relevant data, it would be more accurate to assume a Markov model for $\gamma^i(t)$ and $Q(t)$ of the form

$$Q(t+1) = f(Q(t), w(t))$$

$$\gamma^i(t+1) = h(\gamma^i(t), v(t))$$

where f, and h are deterministic functions and $w(t)$ and $v(t)$ are parametric white noises, i.e.

$$E(w(t)w(s)) = 0,\ s \neq t\ ;\ E(v(t)v(s)) = 0\ ;\ s \neq t$$

For example, suppose we assume

$$\gamma^i(t+1) = A(t)\ \gamma^i(t) + h(t)\ w_p(t)$$

where $A(t)$, $b(t)$ are constants to be determined, $w(t)$ is a wide sense white noise process with zero mean and variance $E(w^2(t)) = 1$.

From above we have

$$E(\gamma^i(t+1)) = \alpha_0 + \alpha_1(t+1)$$

$$= A(t)\ E(\gamma^i(t)) = A(t)(\alpha_0 + \alpha_1 t).$$

Or,

$$A(t) = 1 + \alpha_1/(\alpha_0 + \alpha_1\ t)$$

Moreover,

$$E(\gamma^{i^2}(t+1)) = \sigma_\gamma^2 + [\alpha_0 + \alpha_1(t+1)]^2$$

$$= A^2(t)(\alpha_0 + \alpha_1 t)^2 + b^2(t)$$

and we compute $b^2(t) = \sigma_\gamma^2$.

So this elementary Markov model of the evolution of $\gamma^i(t)$ is

$$\gamma^i(t+1) = [1 + \alpha_1(\alpha_0 + \alpha_1 t)^{-1}]\gamma^i(t) + \sigma_\gamma\ w(t)$$

which is obtained entirely from the known data $(\alpha_0, \alpha_1, \sigma_\gamma^2)$.

In a similar way we may model the evolution of the capital/output ratio $Q(t)$ as

$$Q(t+1) = [1 + \beta_1(\beta_0 + \beta_1 t)^{-1}]Q(t) + \sigma_Q\ v(t)$$

in the sense that the solution to this equation exhibits the same mean and variance behavior computed for $\{Q_{(t)}\}$ if $v'(t)$ is a white noise with normalized variance $E[v^2(t)] = 1$.

The auto correlation function for $\gamma(t)$ is

$$E(\gamma(t)\gamma(s) = \begin{cases} A(t)\ldots A(s)R_\gamma(s,s) & t \geq s \\ R_\gamma(t,t)A\ (t)\ldots A\ (s) & s \geq t \end{cases}$$

with

$$\dot{R}(s,s) \triangleq E(\gamma(s)\gamma(s)$$

$$= A(s)\ldots A(0)E(\gamma(0)\gamma(0)) \quad A(0)\ldots A(s)$$

$$+ \sum_{\ell=0}^{s-1} E[\prod_{k=\ell}^{s=1} A^2(k)]$$

Returning to the capital equation

$$K_{t+1} = K_t[(1 - \delta) + \gamma_t/Q_t]$$

$$K_{t+1} = K_t(1 - \delta) + \gamma_t/Q_t\ K_t$$

$$Q_{t+1} = B(t)Q_t + c(t)w_t$$

$$\gamma_{t+1} = A(t)\ \gamma_t + b(t)v_t$$

where

$$A(t) = [1 + \alpha_1(\alpha_0 + \alpha_1\ t)^{-1}];\ b(t) = \sigma_\gamma^2$$

$$B(t) = [1 + \beta_1(\beta_0 + \beta_1\ t)^{-1}];\ c(t) = \sigma_Q^2$$

3.0 Structural Errors from the Trade Balancing Mechanisms:

In this section we present some preliminary analysis on another source of error in the Economic Model itself, "structural errors" from the assumptions of a specific functional form for the *a posteriori* trade balancing mechanism. Specifically, in section 3.1 we describe the mathematical form of the trade balance mechanism. In section 3.2 we describe a preliminary estimate of the magnitude of the potential errors generated by the artificial assumptions set out in section 3.1. In section 3.3 we consider the world trade matrix which provides the coupling between the regions of the Economic Model. This matrix is also computed in a rather arbitrary fashion, and we examine briefly the effects of some of the steps in this construction.

3.1 Trade Balance Mechanism:

The economic sector of the world model includes a mechanism for balancing world trade. As several features of this mechanism are rather arbitrarily structured, this portion of the model must be examined for the nature of errors it generates.

The basic procedure for balancing world trade and generating regional imports and exports is as follows:

A. Regional Model

Recall from section 1.1 the basic equations (1 - 8) of the economic model of one region, repeated here for convenience

(1) $$K(t+1) = [(1 - \delta) + \gamma^{i}(t)/Q(t)]K(t)$$

(2) $$Y(t) = K(t)/Q(t)$$

(3) $$X(t) = \gamma^{x}(t)\ Y(t)$$

(4) $$M(t) = \gamma^{m}(t)\ Y(t)$$

(5) $$I(t) = \gamma^{i}(t)\ Y(t)$$

(6) $$C(t) = \gamma^{c}(t)\ Y(t)$$

(7) $$G(t) = \gamma^{g}(t)\ Y(t)$$

(8) $$Y(t) = C(t) + I(t) + G(t) + X(t) - M(t)$$

B. Total World Trade:

The World Model consists of ten distinct regions, with the economy of each region modelled by the equations listed above. Putting $X_k(t)$, $M_k(t)$ as the exports and imports in year t from region k = 1, 2, ..., 10 the total world trade is described by the sums

(9) $$TWX(t) = \sum_{k=1}^{10} X_k(t)$$

(10) $$TWM(t) = \sum_{k=1}^{10} M_k(t)$$

To conform to reality we must have

(11) $$TWM(t) = TWX(t) \quad t = 0, 1, 2, \ldots$$

which may not happen due to modelling errors.

C. Corrections of Trade Imbalance:

In the event that equality does not hold in (11), the following procedure is used

(a) Regional exports are held constant and regional imports are modified so that $TWX(t) = T\tilde{W}M(t)$. ($(\tilde{\cdot})$ denotes modified)

(b) Regional imports are modified by allocating 50% of the difference $\Delta T(t) = TWX(t) - TWM(t)$ to the regions, proportional to the volume of regional imports. The remaining 50% of the difference is allocated equally among the regions.

(c) After balancing regional imports and exports there is no guarantee that the total regional expenditures will be balanced as in equ. (8).

If there is imbalance, the difference

$$(12)\qquad D_k(t) = (Y_k(t) - I_k(t) - X_k(t) + \hat{M}_k(t)) - (C_k(t) + G_k(t))$$

is divided proportionally between C_k and G_k.

Remark: This procedure was developed by trial and error, comparing generated trajectories with historical data, and is artificial in the sense that it does not correspond to "physical properties" of the economic system. Hence, it must be examined critically as a source of parametric and structural errors.

D. Mathematical Summary of Balancing Procedure:

We summarize the effects of the balancing procedure on the regional variables as follows:

Let

$$(13)\qquad \Delta T(t) = TWX(t) - TWM(t)$$

Then from step (b) in paragraph C. we have the adjusted regional imports are

$$(14)\qquad \hat{M}_k(t) = \frac{1}{2}\,\Delta T(t)\,\left(\frac{M_k(t)}{TWM(t)}\right) + \frac{1}{2}\,\Delta T(t)/10 + M_k(t)$$

From step (c) the regional balance equation must be adjusted. Let

$$(15)\qquad D_k(t) = [Y_k(t) - I_k(t) - X_k(t) + \hat{M}_k(t)] - [C_k(t) + G_k(t)]$$

$$= \tilde{M}_k(t) - M_k(t)$$

Then the new values of $C_k(t)$ and $G_k(t)$ are

(16) $$\tilde{C}_k(t) = D_k(t) \cdot \left[\frac{C_k(t)}{C_k(t) + G_k(t)}\right] + C_k(t)$$

(17) $$\tilde{G}_k(t) = D_k(t) \cdot \left[\frac{G_k(t)}{C_k(t) + G_k(t)}\right] + G_k(t)$$

Thus, the economy of region k, after trade has been balanced, is described by the variables

$$[K_k(t),\ Y_k(t),\ I_k(t),\ X_k(t),\ \tilde{M}_k(t),\ \tilde{C}_k(t),\ \tilde{G}_k(t)]$$

3.2 Error Analysis in the Trade Balance Feature:

A. Error Types:

Two basic species of errors are introduced into the economic model by the trade balance mechanism.

(1) Parametric modelling errors. These are due to statistical errors in the estimation of the parameters (γ_k^x, γ_k^m, SC) and others associated with the trade model.

(2) Structural errors: By this term we mean errors introduced by those portions of the balancing mechanism which were conceived from *ad hoc* methods; i.e., the allocation of the imbalance between total world imports and exports among the regions, and the computation of the trade matrix.

The "parametric errors" can be treated using the standard methods developed to treat the dynamical model of each individual region, though the computations are more complex. The structural errors are evidently of a fundamentally different character, and they require new methods for a successful analysis.

Accordingly, we turn our attention to them.

B. Structural Errors Generated by the Trade Balancing Procedure:

Recall from section 1.2 our definition of the output vector of the economic model for region k. (equ. (2) of sec. 1.2)

$$\underline{p}_k(t) = [Y_k(t), I_k(t), C_k(t), G_k(t), X_k(t), M_k(t)]'$$

$$= \underline{d}_k(t)\ K_k(t)$$

The trade balancing mechanism consists of two functionals: $f(\cdot)$ which adjusts regional imports $M_k(t)$, $k = 1, \ldots, 10$ to $\hat{M}_k(t)$ so that $TW\hat{M}(t) = TWX(t)$ formally,

(18) $$f[\underline{M}(t)] = \underline{\hat{M}}(t)$$ (see (14) in 3.1)

and a second function $g(\cdot)$ which adjusts $C_k(t)$ and $G_k(t)$ to $\tilde{C}_k(t)$ and $\tilde{G}_k(t)$ to balance regional expenditures

(19) $$\begin{bmatrix} \tilde{C}_k(t) \\ \tilde{G}_k(t) \end{bmatrix} = g[M_k(t), \hat{M}_k(t), C_k(t), G_k(t)]$$

The functionals f and g are constructed by rather arbitrary procedures based on trial and error fitting to historical data and, as a consequence, the adjusted values $\hat{M}$, $\tilde{C}$, $\tilde{G}$ reflect this arbitrariness. A mathematical measure of the extent of this arbitrariness would serve to indicate the magnitude of the deviation of adjusted variables from real quantities. In specific terms then, we would like to determine whether or not the functions f and g are continuous and, if so, to estimate their modulus of continuity in terms of the parameters defining the functions f and g. Finally, by multiplying the modulus by the variances of the elementary parameters (δ, γ, Q, etc) involved we may determine in a crude fashion the effects on the adjusted variables of parametric errors propagated by the state equation.

From equation (14) in section 3.1 we have at year t

$$\hat{M}_k = M_k + 1/2\ \Delta T(.1 + M_k/TWM)$$

with

$$\Delta T = TWX - TWM = \sum_{k=1}^{10} X_k - M_k.$$

For each k, we identify the function

$$\hat{M}_k = f_k(\underline{M}, \underline{X})$$

where we have again introduced the 10-vectors $\underline{M}$ and $\underline{X}$ with components M_k, X_k. From this expression we may define

$$\hat{\underline{M}} = \underline{f}\ (\underline{M}, \underline{X})$$

where $\underline{f}(\cdot)$ is the vector-valued function with components $f_k(\cdot)$, $k = 1,\ldots,10$.

From these expressions we compute the Jacobian $\nabla \underline{f}(\underline{M}, \underline{X})$ as the 10 by 10 matrix with entries $(\nabla f)_{k\ell} = \partial f_k/\partial M_\ell$ where

$$\frac{\partial f_k}{\partial M_\ell} = -\frac{1}{20} + \frac{M_k \cdot \Delta T}{(TWM)^2} - \frac{M_k}{TWM} \; ; \; k \neq \ell$$

$$= 1 - \frac{1}{20} + \left(\frac{1}{TWM} - \frac{M_k}{(TWM)^2}\right)\Delta T - \frac{M_k}{TWM} \; ; \; k = \ell$$

Clearly, these expressions are bounded for each k and ℓ.

To ascertain the modulus of continuity of $\underline{f}(\cdot)$ we compute

$$||\nabla f|| \triangleq (\text{trace } [\nabla f(\nabla f)'(\underline{M}, \underline{X})])^{1/2} \quad ((\cdot)' \text{ denotes matrix transpose})$$

for nominal values of $\underline{M}(t)$ and $\underline{X}(t)$; in particular, the mean values $E[\underline{M}(t)]$ and $E[\underline{X}(t)]$ are appropriate. These, of course, may be readily estimated in terms of the expression for $E\underline{K}(t)$ which we have given in previous sections. And these expressions, combined with the elementary estimation techniques we have employed, may be used to derive estimates on the mean and variance of the modulus $||\nabla f||$.

In a similar way we may treat the function $g(\cdot)$ which adjusts regional expenditures to satisfy the regional balance equation. From (15) and (16) above we have for each t

(20) $$\tilde{C}_k = C_k + D_k \cdot [C_k/(C_k + G_k)]$$

(21) $$\tilde{G}_k = G_k + D_k \cdot [G_k/(C_k + G_k)]$$

(22) $$D_k = \tilde{M}_k - M_k$$

and these are summarized formally in (19). Let us denote the component of $g(\cdot)$ which represents equation (20) as $g^c(\cdot)$. Similarly, let $g^g(\cdot)$ denote the component representing equation (21). We compute

(23) $$\frac{\partial g^c}{\partial C_k} = 1 + D_k \left[\frac{G_k}{(C_k + G_k)^2}\right]$$

(24) $$\frac{\partial g^g}{\partial G_k} = 1 + D_k \left[\frac{C_k}{(C_k + G_k)^2}\right]$$

Moreover, we may approximate D_k by

(25) $$D_k \simeq [f_k(\underline{M}, \underline{X}) - M_k][1 - \frac{\partial f_k}{\partial M_k}]^{-1}$$

which enables us to approximate the right-hand sides of (23, 24) by expressions in terms of the unadjusted system variables.

The cross terms are

$$\frac{\partial g^c}{\partial G_k} = - \frac{D_k C_k}{(C_k + G_k)^2}$$

$$\frac{\partial g^g}{\partial C_k} = - \frac{D_k G_k}{(C_k + G_k)^2}$$

Again we estimate the modulus of continuity for the internal balancing function g by

$$||g_k|| = (\text{ trace } [\nabla g_k (\nabla g_k)'])^{1/2}$$

with $$(\nabla g) = \begin{bmatrix} \partial g^c/\partial C_k & \partial g^c/\partial G_k \\ \partial g^g/\partial C_k & \partial g^g/\partial G_k \end{bmatrix}$$

And we obtain an estimate for the overall system balancing function by summing the moduli for each region; formally,

$$||g|| = \sum_{k=1}^{10} ||g_k||.$$

3.3 Distribution of Trade - World Trade Matrix:

A. Computation of the Trade Matrix:

After the balancing procedure above has been executed, the percentage of trade one region does with another can be determined. The model uses a world trade matrix to accomplish this step. The matrix T(t) is 10 x 10 with elements $t_{ij}(t)$ which are the fractions of the j^{th} region's imports which come from the i^{th} region. Let $\underline{\tilde{M}}(t) = [\tilde{M}_1(t),\ldots, \tilde{M}_{10}(t)]'$ (a 10-vector) and $\underline{X}(t) = [X_1(t),\ldots,X_{10}(t)]'$. Then

$$\underline{\tilde{X}}(t) = T(t)\underline{\tilde{M}}(t) \tag{1}$$

That is, the trade matrix multiplied by the import vector yields the export vector. Note that we must have

$$\sum_{i=1}^{10} t_{ij}(t) = 1 \qquad 1 = 1,2,\ldots,10. \tag{2}$$

The trade matrix for a particular year T(t) is obtained by forming

$$\hat{T}(t) = T(t-1) + SC \tag{3}$$

where the stepping constant matrix SC has as elements the mean yearly changes in the historical trade matrix elements as determined from available data. The matrix $\hat{T}(t)$ is distorted from the "true" trade matrix T(t) in two ways

(i) The columns of $\hat{T}(t)$ may not sum to one.

(ii) $\hat{T}(t)\underline{\tilde{M}}(t)$ may not be equal to $\underline{X}(t)$, with $\underline{\tilde{M}}$ and $\underline{X}$ as defined above.

Two adjustments on $\hat{T}(t)$ are made to produce a matrix T(t) which does satisfy (i) and (ii).

(a) New column elements $\tilde{t}_{ij}$ are formed from the elements of $\hat{T}$, denoted by $\hat{t}_{ij}$, as follows.

$$\tilde{t}_{ij} = \hat{t}_{ij}/(\sum_{k=1}^{10} \hat{t}_{kj}) \quad i, j = 1,\ldots,10$$

Of course, $\sum_{i=1}^{10} \tilde{t}_{ij} = 1,\ j = 1,\ \ldots,\ 10.$

(b) To correct deviations from computed exports as noted in (ii), the intermediate matrix $\hat{T}$ is adjusted further in a non-linear fashion. First, form

$$\underline{\tilde{X}}(t) = \hat{T}(t)\underline{\tilde{M}}(t)$$

with $\underline{\tilde{M}}(t)$ the adjusted import vector defined previously. Compute

$$e(t) = \frac{\sum_{k=1}^{10} |\hat{X}_k(t) - X_k(t)|}{TWX(t)}$$

If $e(t) > \varepsilon$, for some small ε, then the difference $|\hat{X}_k - X_k|$ is distributed equally among the k^{th} row of the trade matrix, forming

$$\hat{\hat{t}}_{ij} = \hat{t}_{ij} + \frac{1}{10} |\hat{X}_i - X_i|$$

The columns are then balanced again and the process repeated until the error $e(t)$ is less than ε. The final iterate is taken as the trade matrix T(t). Its columns nearly (modulo ε) sum to one and when multiplied by $\underline{M}(t)$ it produces $\dot{X}(t)$ within an error of ε in each (regional) component.

Appendix: Note on Linear Least Squares Approximation

From Johnston, Econometric Methods Chapter 2, we have the following procedure for fitting a line to a set of data points using simple least squares techniques. Given a set of index points {1, 2, ..., N} and a set of sample values $\{Y_1, Y_2, \ldots, Y_N\}$ we assume

$$Y_k = \alpha + \beta k + u_k \qquad k = 1, 2, \ldots, N$$

where α and β are to be determined and u_k is a zero mean random variable with constant (unknown) variance σ_u^2 for each k.

We seek an approximation of the form

$$\hat{Y}_k = \hat{\alpha} + \hat{\beta}\, k$$

which minimizes

$$\sum_{k=1}^{N} e_k^2 \triangleq \sum_{k=1}^{N} (Y_k - \hat{Y}_k)^2$$

$$= \sum_{k=1}^{N} (Y_k - \hat{\alpha} - \hat{\beta} k)^2$$

The best choices of $\hat{\alpha}$ and $\hat{\beta}$ satisfy

$$\sum_{k=1}^{N} Y_k = N\hat{\alpha} + \hat{\beta} \sum_{k=1}^{N} k$$

$$\sum_{k=1}^{N} kY_k = \hat{\alpha} \sum_{k=1}^{N} k + \hat{\beta} \sum_{k=1}^{N} k^2$$

which may be readily solved. Johnston gives the formulas

$$\hat{\beta} = \frac{\sum_{k=1}^{N} x_k y_k}{\sum_{k=1}^{N} x_k^2}$$

$$\hat{\alpha} = \overline{Y} - \hat{\beta}\overline{X}$$

where $\overline{X} = \frac{1}{N} \sum_{k=1}^{N} k = \frac{N-1}{2} = \frac{N(N-1)}{2N}$

$$\overline{Y} = \frac{1}{N} \sum_{k=1}^{N} Y_k$$

$$y_k = Y_k - \overline{Y}, \quad x_k = k - \overline{X}$$

A related parameter is

$$r = \frac{\sum_{k=1}^{N} k y_k}{N\, s_x\, S_y} \; ; \quad s_x = \sqrt{\frac{x_k^{\,2}}{N}} \; ; \quad s_y = \sqrt{\frac{y_k^{\,2}}{N}}$$

which also satisfies

$$r^2 = 1 - \frac{\sum_{k=1}^{N} e_k^{\,2}}{\sum_{k=1}^{N} y_k^{\,2}}$$

The remaining unknown is the variance σ_u^2 which measures the deviation about the linear relation $\hat{\alpha} + \hat{\beta}k$. From Johnston, p. 37 we have an estimate $\hat{\sigma}_u^2$ given by

$$\hat{\sigma}_u^2 = \frac{\left(\sum_{k=1}^{N} y_k^2\right)(1 - r^2)}{N - 2}$$

Example 1: The estimate of $\gamma_i(t)$, the investment ratio.

From Kominek, p. 214 we have the historical investment ratios from data collected elsewhere. Specifically, for North America the historical data are

Year	γ_i	Year	γ_i
1950	.198774	1961	.169641
51	.179005	62	.171549
52	.171547	63	.171545
53	.173866	64	.174814
54	.180946	65	.179205
55	.184576	66	.177265
56	.188702	67	.170151
57	.182005	68	.172878
58	.175781	69	.172834
59	.179525	1970	.168949
60	.175446		

Defining $Y_k = \gamma_i(k)$ we have

$$\overline{Y} = .177$$

$$\sum_{k=1}^{21} y_k^2 = .1017 \times 10^{-2}$$

$$r^2 = .3446 \qquad \text{(Kominek, p. 100)}$$

$$1 - r^2 = .6554$$

$$\hat{\sigma}^2 = .3506 \times 10^{-4}$$

$$\hat{\alpha} = .183894 \; ; \; \hat{\beta} = -\ .000680 \; [1,\ p.\ 100]$$

In summary we have

$$\gamma_i(k) = .183894 - .000680 \cdot k + u$$

and

$$\text{mean } \gamma_i \cong E[\gamma_i(k)] = .183894 - .000680 \cdot k$$

$$\text{variance } \gamma_i \cong \hat{\sigma}^2 = .3506 \times 10^{-4}$$

Example 2: In a similar fashion we compute the statistics of the capital output ratio Q(t) for North America as

$$Q(k) = 3.804873 - (.044515)k + u$$

with

$$\text{variance } \sigma_Q^2 = \sigma_u^2 = .01093$$

$$\text{mean } Q(k) = 3.804873 - (.044515)k.$$

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References:

1. Kominek, K., Construction of a World Economic Model, M.S. Thesis Systems Research Center, Case Western Reserve University, January 1974.

2. Johnston, J., Econometric Methods, McGraw-Hill, New York, second edition, 1972.