SP-74-1

INTERNATIONAL INSTITUTE FOR IIASA APPLIED SYSTEMS ANALYSIS

SYMPOSIUM PROCEEDINGS

MULTILEVEL COMPUTER MODEL OF WORLD DEVELOPMENT SYSTEM

EXTRACT
from the
PROCEEDINGS OF THE SYMPOSIUM
HELD AT IIASA, LAXENBURG
April 29 – May 3, 1974

M. MESAROVIC & E. PESTEL, EDITORS

VOLUME I

SCHLOSS LAXENBURG
A-2361 AUSTRIA

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Preface

Upon invitation of the International Institute of Applied Systems Analysis (IIASA) a seminar was held in Baden (Austria) from April 29 to May 3 1974 in which the Regionalized Multilevel World Modeling Project was presented to and discussed by more than 1oo scientists of various disciplines from all parts of the world.

The scientific foundation for the research was laid nearly years ago, when the authors decided to develop a project concerned with the analysis of global issues which would realistically take into account the diversity of the many different world regions and would deal with issues concretely, rather than in abstract terms. We hoped thus to furnish political and economic decision-makers in various parts of the world with a comprehensive global planning tool. The project, generously supported by the Volkswagen Foundation, was carried out chiefly at the Systems Research Center of the Case Western Reserve University in Cleveland, Ohio, USA and at the Technical University of Hannover, Germany, aided by many collaborators and consultants from other institutions in USA, Germany, France, Mexico, The Netherlands, Italy, Switzerland and Japan.

From the nearly thirty research reports submitted to the symposium in Baden an extract was made in the form of a technical report, presented herewith for wider distribution by IIASA. We hope that the publication of this technical report will contribute to a rational discussion of our and other world modeling efforts as well as of the issues treated in our book "Mankind at the Turning Point".

The seminar at IIASA was sofar the last in a series of conferences at which our project was exposed to the scrutiny of the scientific community. Although our work by no means terminates with the publication of this report and the scientific and technical reports referred to above, we believe that our findings and the general insights gained through intense preoccupation with the model, its data base, and the pressing issues of our time, amply justify their publication already at this time.

To IIASA we should like to extend our thanks for having served as a forum for the presentation and discussion of our research.

M. Mesarovic — Cleveland
E. Pestel — Hannover

September 1974

A - 1 MOTIVATION, OBJECTIVES, AND CONCEPTUAL FOUNDATION

Eduard Pestel

APRIL 1974

The project, aimed at the development of a scientifically based computer model of the world development system, supported by all available data whose first public disclosure is presented at this symposium, was initiated three years ago by Professor Mesarovic and myself. Unquestionably, that was to be a major effort and a strong motivation was needed to carry it out. The motivation which urged us then and which still drives us and our collaborators has a number of diverse aspects:

First, there is the conviction that the world will have to face a cluster of crises of unprecedented type and magnitude which might very well appear before the end of the century, and possibly even more overwhelmingly thereafter, in ever faster succession.

It is this cluster which The Club of Rome has characterized as the "world problematique" in order to draw attention to the uniqueness and magnitude of the problems involved and to the extreme difficulty in understanding the evolving situation, not to mention finding a remedy and means to avoid disaster. What are some primary characteristics of the world problematique which set it apart from earlier events in world history?

1) The problems are global:for some of them, as e.g. in the case of the energy crisis, this is quite obvious. For some others, as

e.g. the threat of starvation in particular regions, the global character is felt either through socio-political or economic interdependence. The global character of the problems makes them very difficult to solve from the national and regional levels which have, more often than not, conflicting concerns.

2) The changes are felt through the entire society. Economic, technological, environmental, socio-political and many other aspects are interacting in such a way that, what might appear as a desirable strategy in one domaine, makes the situation only worse in others. It seems, as it was often stated, that everything is related with everything else. This hinders the solution of problems by traditional means designed solely within one domaine, i.e. technology, economics, environment, etc.

3) There is a conflict between short and long range problems and solutions. A short range solution often only compounds the long range problem, makes it worse when it reappears the second time around. Therefore attempts to arrive at a long term solution by a succession of short term solutions would fail.

4) There are considerable delays, measured in years if not decades, between the time when a corrective action is applied and when its remedial action is felt. For example, if a successful population policy brings the fertility rate to equilibrium level, it will take 30-50 years and possibly more, until the population itself would reach equilibrium. Delaying the action until the "last minute"

will nullify any beneficial influence it might have had.

5) Traditionally, crises were the results of negative actions by man or nature. The current crisis, in contrast, seems to be the result of actions which are traditionally considered as most desirable; e.g. to have a large family, or to use as much energy as possible to save human labor, or to exploit nature to the utmost for the benefit of man. The adjustment will have to involve changes in the basic norms- and goals-system traditionally considered as sacrosanct.

These essential aspects of the world problematique led us from the very beginning of our work to look at the world as a whole, and not just at national or regional problems and crises in isolated fashion.

Next, let me make a few remarks about the history of our project, because this leads up to our second basic motivation for undertaking this challenging enterprise.

In 1970 The Club of Rome was in search for a methodology, both practical and comprehensive, which could be applied to its envisaged global modelling project on "The Predicament of Mankind". During that process Prof. J. Forrester made a presentation of his industrial and urban dynamics methodology to the Club of Rome at its first Plenary Meeting in Bern. Support was obtained from the Stiftung Volkswagenwerk to enable him to carry out a preliminary test project. He developed the first "world dynamics" model in rather abstract terms and then entrusted its further refinement and documentation to his student and associate,

D. Meadows. This led ultimately to the development of the model "World 3" which was presented for a general reader's audience in the highly successful book "The Limits to Growth".

When I first, so to say, inspected in early 1971 the Meadows project, half a year after it had gotten underway, in my capacity as a member of the Executive Committee of The Club of Rome, I realized with some disappointment that the project, when completed, would not be able to resolve basic questions within the world problematique as envisaged initially by The Club of Rome. This seemed not to be due to any lack of effort on the part of the participating researchers, but rather to be due to the inherent shortcomings of the methodological approach. I searched therefore for a more sophisticated approach that would have a better chance to reach the goals which The Club of Rome had set itself when it conceived its major project "The Predicament of Mankind". This led to the discussion with Professor Mesarovic whose book on large scale and complex systems had appeared about a year before,and who also has just completed the manuscript for another book on the general systems theory.*

Prof. Mesarovic and myself designed then the first stages of what later became a rather sizeable project aimed at making a scientifically based and solid contribution to the problematique as defined by The Club of Rome. The effort was also supported by the Volkswagen Foundation. Obviously,

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* M.D. Mesarovic: "Theory of Multi-Level Hierarchical Systems"
M.D. Mesarovic: "General Systems Theory"

this was to be a much more ambitious attempt than the Forrester-Meadows study and would have to take much more time. At this symposium we shall publicly describe for the first time and in full our findings so far.

Our presentation over the next days will provide enough material to support this contention. Here, let me illustrate only what difference it makes in terms of the essential theses which embody the conclusions, results of analysis, and the strategy for remedy of the world situation, using on the one hand the industrial-urban dynamics methodology of Forrester, and the multilevel, hierarchical systems methodology in our project, on the other.

The Forrester-Meadows theses regarding the world problemtique can roughly be summarized as follows:

Theses Forrester-Meadows

1) The world can be viewed as one system, consisting of a number of global variables.
2) The system will collapse sometimes in the middle of the next century, if present trends continue.
3) To prevent collapse, an immediate slowdown of economic and population growth must be initiated leading to no-growth in a relatively short period of time.

On the other hand, the results of the analysis in our project, for the sake of contrast can be presented in form of the following theses:

Our Theses

1) The world can be viewed only in reference to the prevailing

differences in culture, tradition, and economic development. The world can be viewed as a system only in terms of interacting regions: a monolithic view of such a system is misleading.

2) Rather than collapse of the world system as such, catastrophies or collapses on a regional level would occur possibly even long before the middle of the next century, however in different regions, for different reasons and at different times. Since the world is a system, such catastrophies will be felt profoundly throughout the entire world. Causes for such crises and potential catastrophies are the population, food and economic relationships in Africa and South Asia;energy and raw material scarcity and production growth in the developed world;employment and population relationships in Latin America, etc.

3) The solution to such catastrophies of the world system is possible only in the global context to resolve the conflicts between the regions by appropriate global actions. If the framework for such joint action is not developed, none of the regions would be able to avoid the consequences. For each region, its turn would come in due time.

4) Such a global solution could be implemented only through selective and balanced growth, not uniform, but greatly differentiated throughout the world. From the viewpoint of the total world system this means growth analogous to organic growth rather than undifferentiated growth. It is irrefutable that the second type of growth is cancerous and would ultimately be fatal.

5) The delays in devising such global strategies are not only detrimental and costly, but deadly. It is in this sense that we are truly talking about a "strategy for survival".

With these theses in mind, Prof. Mesarovic and myself then set out to formulate the following two basic objectives in our project:

1) To develop a system's representation of the world development process which can provide us with an insight as to the causes and effects within such a system, and subsequently allow us an assessment of alternative sequences of events which might take place in the future.

2) To develop a planning and decision-aiding tool which can be used for the evaluation of alternative policies and be applied in practice when searching for solutions of various problems involved in the problematique.

Both these objectives require a computer based model of the system involved. This is no mean task and we shall have to say quite a bit as to the methodology, data, assumptions, and other aspects of the model-building process.

What are the goals we want to accomplish with our project? They are again twofold: The first goal is action- oriented. We are convinced in the reality and gravity of the crisis conditions which are enveloping the world system, as well as in the urgency of searching for solutions and indeed applying them. Having this conviction, it is our responsibility to do our part in initiating such a process. As a matter of fact, we hope that the computer based planning and decisionaiding tool developed within our project will be actually used and thereby influence future developments. In this respect our project is not an academic exercise but the response of concerned activists. The ultimate success of the project will have to be measured in this respect by the influence, the effect and the consequences the project will have in practice. The second goal is academic. We do not share the prevailing cynicism regarding responsible policy and decision makers. Of course, they act too often in their own interest and with the time horizon for which they are elected or appointed. But it is also true that they are not being helped to a sufficient degree by the academic community to plan and act otherwise. Indeed, it might be argued that by and large the decision-makers are perhaps more aware of the problematique than the community of scientists. There are possibly two reasons for this: (1) The academic concerns revolve around academic disciplines. Yet, the real world, particularly under crisis conditions, is not divided into nice compartments as our universities are. (2) The research in academic disciplines is by tradition analytic and oriented toward the past. The world problematique however requires an orientation towards the future and indeed over a rather long time horizon. It is surely not to be denied that the future is conditioned by the past, by historical patterns of development. However, it must be expected to be also fundamentally different and its analysis requires a different mental attitude and a different methodological approach than is applied to the classical scientific domaines. Future events will take place under conditions fundamentally different from the past, whose texture is far more interwoven than ever before. It is therefore necessary to develop a basis for such research on an interdisciplinary and holistic basis, and it is our second goal, by developing a solid foundation for the study of future development processes, to enable the mobilization of many good minds in academia not only for a better understanding of these problems which are possibly the most challenging in our aera, but also for a salutory engagement in the search of solutions. I might add here: It seems that the great turnout for this conference offers proof that this second goal is already being approached.

When developing a model for a real life system one does not describe all the relationships which actually exist. In principle, there would be no end to such a process. Rather, one considers only those relationships which seem to be relevant for a certain objective, i.e. for a certain issue or problem of interest. The validity of the model and the usefulness of the analysis based on such a model depend on how judiciously one selects the relevant relationships. In the case of the world system we are interested in a very long term development, e.g., in the order of 50 years, and the relationships selected - economic, social, technological, ecological, etc. - reflect that fact. So it is not a "model of the world" that we are constructing but rather a model of certain world-wide relationships in region - specific terms which are of importance for the assessment of alternative long terms trends in the world systems development.

If we are to deal effectively with the crises of the present, we must understand their origin and nature, their linkages and interactions. It is our intention in this book to analyze the crises in the world development in concrete rather than abstract terms; otherwise our analysis will be just another academic exercise, of which there is no shortage. Specifically, we shall ask the following questions:

1. Are the crises - energy, food, raw materials, etc. - persistent, or are they aberrations due, possibly, to oversight or neglect?
2. Can the crises be solved within local, national, or regional boundaries, or must truly lasting solutions be effected within a global framework?
3. Can the crises be solved by traditional measures which have always been confined to an isolated aspect of social development, such as technology, economics, politics, etc. - or must the strategy for solution be more comprehensive, involving all aspects simultaneously?
4. How urgent is the resolution of the crises? Will delay buy time and make the implementation of solutions less painful, or are solutions made more elusive by delay?
5. Is there a way to solve the total crises by cooperation without undue sacrifice on the part of any of the constituents of the world system; or is there the danger that some could gain permanently by seeking confrontation with their partners in the global context?

Whenever one deals with the sort of problems and questions outlined above, a decision concerning the time-horizon of the study has to be made. Most of the so-called "long looks" into the future do not extend beyond the year 2000. If things seem manageable by then, everything is proclaimed satisfactory. Granted, the degree of uncertainty grows with each extension of time. But, as will be demonstrated time and again in this report, the dynamics of the world system require twenty years or more for the effects of change to be accurately measured and fully revealed. Moreover, the delays involved in the implementation of decisions can be formidable. Our analysis therefore extends over a period of 50 years.

The results of the computer analysis reported later on provide answers to the basic questions posed above on the conditions required for the solution of the major world crises and the strategies leading to that solution. In particular, we have seen that?

1. The current crises are not temporary, but rather reflect a persistent trend inherent in the historical pattern of development.

2. The solution of these crises can be developed only in a global context with full and explicit recognition of the emerging world system and on a long-term basis. This would necessitate, among other changes, a new world economic order and a global resources allocation system.

3. The solutions cannot be achieved by traditional means confined to an isolated aspect of the world system, such as economics. What is really needed is nothing short of a complete integration of all strata in our hierarchical view of world development - that is, a simultaneous consideration of all aspects of mankind's evolution from individual values, norms and attitudes to ecological and environmental conditions.

4. It is possible to resolve these crises through cooperation rather than confrontation; indeed, in most instances cooperation is equally beneficial tc all participants. The greatest obstacles to cooperation are the short-term gains that might be obtained through confrontation. Even if these gains are short-lived and demonstrably lead to long-term losses, there is always a pressure to go after these gains.

What are the immediate first steps which could be taken on a social or individual basis and which can create an atmosphere in which serious attempts to develop master plans for organic growth can be undertaken? On the societal level the necessary changes include:

1. The realization that counterproductivity will be the ultimate consequence of any action confined solely to short-term considerations. This must be accepted as a basic premise in all decision-making processes. Long-term assessment ought to become standard procedure in the consideration of fundamental decisions regarding developmental issues. Only in such a way can organizations - businesses, governments, or international units - actively contribute and consciously influence the emerging world system. Otherwise they might very well become nothing more than passive passengers on a voyage charted by outside forces.
2. The futility of narrow nationalism must be appreciated and taken as an axiom in the decision-making framework. Global issues can be solved only by globally concerted action. For example, any nation that will try to solve the pervasive problem of inflation by actions limited solely to measures within its own boundary will be doomed to disappointment. Similarly, even if only a few countries resist such measures, the effort will almost certainly remain futile.
3. Development of a practical international framework in which the cooperation essential for the emergence of a new mankind on an organic growth path will become a matter of necessity rather than being left to good will and preference. Balance between constituent parts of the world system is needed to achieve that end; among other implications this suggests the need for stronger regional arrangements

and accelerated development in certain parts of the world. Such developments are in the best interest of all partners in the world system.

4. Realization of the overriding importance of the long-term global development crises, as discussed in this report, and willingness to place this highest on the agenda of the issues to be dealt with explicitly by national governments and international organizations. Precisely because the symptoms of these global crises might become fully visible only toward the end of the century, the time to act is now; when the symptoms become clear, the remedy will no longer be possible, as has been characteristic of history in the past; the time to affect that history is now.

Regarding individual values, norms and attitudes, the following lessons seem to be outstanding for the new global ethic implicit in the preceding requirements.

1. A world consciousness must be developed through which every individual realizes his role as a member of the world community. Famine in Tropical Africa should be considered as relevant and as disturbing to a citizen of Germany as famine in Bavaria. It must become part of the consciousness of every individual that the basic unit of human cooperation is moving from the national to the global level.
2. A new ethic in the use of material resources must be developed which will result in a style of life compatible with the oncoming age of scarcity. This will require a new technology of production based on minimal use of resources and longevity of products rather than production

processes based on maximal throughput. One should be proud of saving and conserving rather than of spending and discarding.

3. An attitude toward nature must be developed based on harmony rather than conquest. Only in this way can man apply in practice what is already accepted in theory - that is, that man is an integral part of nature.

4. If the human species is to survive, man must develop a sense of identification with future generations and be ready to trade benefits to the next generations for the benefits to himself. If each generation aims at maximum good for itself, Homo Sapiens is as good as doomed.

Many of you will possibly say:these conclusions are not very original and new. What, however, appears to us to be new in any case is that in our work these are not a - priori statements, but are derived - as a matter of consequence - from our scientific work. We hope ardently that our research will gain credibility with political decision makers and ordinary citizens alike such that the kind of planning and decision - aiding tool which we have begun to provide will eventually be applied to help chart the future path of mankind.

A - 2 METHODOLOGY FOR CONSTRUCTION AND STRUCTURE OF THE MULTILEVEL WORLD SYSTEM MODEL

Mihajlo Mesarovic

APRIL 1974

1. Introduction

To achieve the basic objectives and goals for the project, as stated by Professor Pestel, it was necessary to construct a computer model of the world development system and to design procedures for its effective use. It needs hardly to be mentioned that this is not an easy task; one which requires that careful attention be paid to the methodology, in particular, if one would like to accomplish the objectives in a relatively short period of time rather than embark on an open ended research for research's sake.

What are some of the major difficulties which require methodological attention:

(i) Complexity: The system of concern - the phenomena involved - are no doubt of extraordinary complexity. It is not only the question of size, i.e., the number of variables and relationships, but equally so the lack of "regularity" or "simplicity" in the relationships involved, i.e. the apparent absence of comparatively simple laws underlying the phenomena considered, and finally a multitude of contexts in which the total system as such can be described with equal justification. For example, if the system has a large set of variables governed by probabilistic laws, it can be described in terms of an extremely small number of aggregate indicators, so that in spite of the large numbers involved the "regularity" of the underlying relationships allows tremendous simplification in such a case. Unfortunately, this is not so in the case of the world system.

(ii) Interdependence and Multiplicity of Contexts: The phenomena from different bodies of knowledge, i.e. different scientific disciplines - economics, physics, ecology, etc. - have to be considered in such an undertaking. This knowledge and the corresponding data are derived from different types of observations by different procedures, and within different contexts which makes the establishment of interdependence exceedingly difficult even where these contexts are compatible to a degree. The world system can be viewed from different angles which through historical development have resulted in representations of the system which are not necessarily compatible. Yet, the type of issues of interest in our project requires that many of these views be taken into account simultaneously and interdependently.

(iii) Uncertainties: We are interested in the behavior of the system which involves the human element, and over a long time horizon of, say, 50 years and more. This is not out of academic curiosity, but because the consequences of the decisions involved are felt over such a period and the dynamics of the systems involved has time constants of that order of magnitude. As an example, the consequences of the decision to elect the nuclear option to solve the energy crisis would become fully visible only after 50 years. The uncertainty in considering such time horizons is tremendous yet unavoidable. The problem is compounded by the fact that scientists' inquiry, in general, has been traditionally analytic and past-oriented - concerned with why the events happened as they did, rather than what would or could happen in the future. This future orientation requires a different approach and, on the practical level, a different set of tools and techniques.

(iv) Intangibles: The evolution of the world system will in reality depend on social, political and individual choices made in the case of the physical, economic and other constraints. The evolution of the system involves therefore not only institutional, social and political factors but also the underlying values, preferences and choices of individuals. For example, the prevailing attitude toward material consumption, toward social mobility, toward political participation etc. are examples of factors which are of equal importance for the evolution of the system as the depletion of oil and other resources, the increase in investment or productivity of capital etc. These are the forces which guide the evolution of the system. Many of them cannot be modeled in any of the classical ways.

(v) Comprehension: In general, the advancement of science is based on an improved understanding why certain events take place in reality, rather than on an increased ability to replicate sequences of events as they actually occur. This fact is too often overlooked in the development and use of computer models. Given any set of data, one can - in principle - establish the relationships between them by introducing a sufficiently large number of variables and parameters. But without further discrimination this shows nothing more than that "what happened did actually happen". To be able to use such a model in order to consider what could or would happen in the future, one has to have a 'feel' as to what is important and what is secondary, 'why' the events have happened as they did. To construct a large model in order to study a large scale and complex system might be necessary, but is not sufficient. It is also required to provide an explanation of why the system behaves in a certain way or responds in a certain manner; preferably such an explanation should be as simple as possible and have an intuitive appeal. This is in particular true, if the outcome of the computer model analysis is to be used in actual decision making. It is hard to accept a policy recommendation for action, especially in connection with important and overriding issues, if there is little or no 'explanation' of the rational, which leads to such a conclusion especially if that conclusion is at variance with the intuitive expectations.

(vi) Effectiveness in Use: The social and political issues are often stated in general forms which cannot be directly and uniquely related with specific policies, implementation measures and responses of the system that can be evaluated in quantitative terms. For example, the issue of 'independence in energy resources' for a country or a region translates on a concrete level of actions into a large set of alternatives. All or most of them have to be evaluated in order to decide which one would lead best to the desired goal; furthermore, the methodology must allow the assessment process to yield the answers on the same level - possibly intuitive or verbal - on which the questions are posed.

To meet the challenge posed by the above mentioned difficulties it is quite apparent that one cannot use anyone of the comparatively simple - in the conceptual sense - methodologies as e.g., linear programming, the so-called urban and industrial dynamics and the likes. Rather, a broader systems approach has to be employed which also provides for the use of many of specialized approaches (such as e.g. linear programming), techniques or tools at the appropriate points in the process of inquiry.

Our methodology is based on the multilevel, hierarchical systems theory and the open systems modeling approach. Our methodology does not boil down to an 'algorithm' or to 'formulae' so that 'once all the data are fed in, the solution comes out automatically'. Rather it provides a framework and a set of principles which are used to solve various problems in the conduct of inquiry. Instead of embarking on a broad discussion of that methodology we shall present how it solves some of the key issues, which we had to face in the construction of the model and the planning tool. In this we shall also indicate how the conceptual difficulties mentioned in this section are being dealt with.

2. Stratified Structure in the Complex Systems Modeling

One of the major difficulties in modeling the world system for a study of the world problematique rests in the absolute necessity to consider the phenomena and processes traditionally of concern in different fields of inquiry, (i.e. scientific disciplines) as interacting and comprising a recognizable and unified system. This is a perennial problem of inter-disciplinary efforts.

Traditionally, this problem was solved in two ways: (1) by starting from a representation in a given discipline and bringing in the additional factors by an extension within the same context, using traditional concepts and ideas. For example, this is often done in economics; when the need arises for going beyond a traditional set of economic variables and relationships, one constructs a new 'sector' to 'endogenize' the externalities such as pollution of water, limitations of technology and physical resources etc. A typical example of such an approach is found in some of the Leontieff's input-output models extended to cover the environmental impacts. Such an approach cannot but remain limited by the scope of the original disciplines. (2) by starting from a set of key values and establishing the relationships between them directly from data or assumptions with little if any regard for the understanding and laws as provided within the corresponding scientific disciplines. A typical example of such an approach is the so-called urban or system dynamics. Often such an approach can be relied on only for a rather general qualitative assessment of possible trends, because the available data are ordinarily of little use for such an exercise*.

For our effort we needed a broader and more scientifically based approach. For that end we have used the multilevel, hierarchical systems theory. Rather than embarking on a lengthy theoretical discussion, let us start with a couple of examples:

Assume that we want to model a large scale computer system. That can be done at least in three different ways. One can view the computer as a physical system, which it undoubtedly is, and develop a model in terms of various physical processes involved - electronic, electrical,

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* Just compare the 'standard' runs in Forrester's "World Dynamics", in which the entire input of 'real' data consisted of the world population numbers in 1900 and 1970, and in Meadows' "The Limits to Growth". There is hardly any difference except that Meadows' 'curves' are somewhat steeper due to the larger number of delays built in the model.

mechanical, etc. - or, one can view the computer as an information processing machine and develop an automaton-type model; still differently, one can look at the system as an 'information utility' which is employed in a time-sharing mode of operation. Now, each of these representations is legitimate and true. None is, in principle, preferable to others. It depends on the problem of interest which of these representations is most appropriate. Each of the representations serves a given purpose. Of interest here is to point out that each of the representations refers to the entire system and the difference between them is actually in the terms - concepts and variables - which are used to describe the systems' behavior. We refer in this sense to different contexts in which the systems' behavior is described. In recognition of the fact that each representation refers to the totality of the system - in space and time - the representations are viewed as being in a vertical arrangement, as shown in Fig. 1, forming a hierarchy. In order to distinguish this type of hierarchy from others, each level in this hierarchy is termed a stratum and the entire system - or rather its representation - is referred to as a 'multistrata system' or a 'stratified system' or a 'system with a multistrata structure'. Obviously the behavior of the system is better understood, if more strata are identified and analyzed.

It is also apparent that the stratification is not necessarily in the system as such, but rather reflects our views, interests, and interpretations. However, the stratified structuring is more than an artifact developed for an efficient description of a complex system. It is recognized as a fundamental characteristic of nature. Indeed, hierarchical arrangements in nature are well appreciated. A biological system, e.g. can be viewed

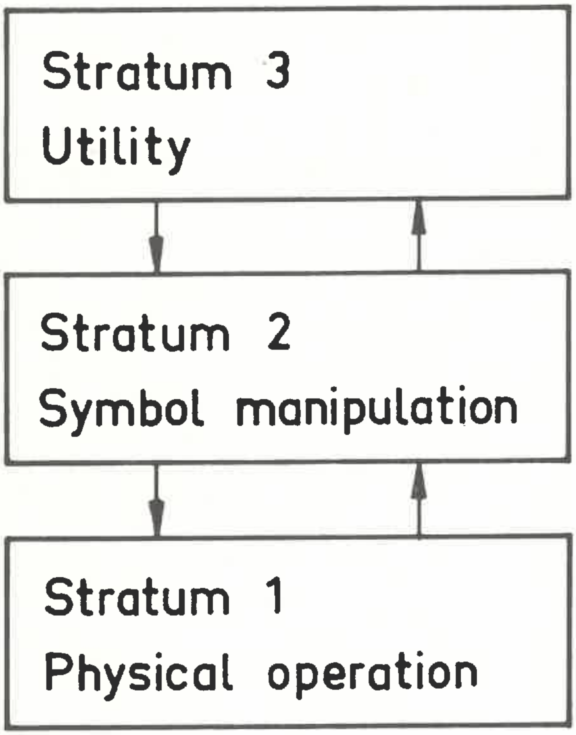

Stratum 3
Utility
Stratum 2
Symbol manipulation
Stratum 1
Physical operation

Figure 1

on the nuclear level, atomic level, chemical level, subcellular level, cellular level, organ level and the level of the entire organism. Each of these levels is legitimate and contributes to our understanding of the system involved. We are fully ignorant as to why nature appears to be hierarchically structured. Yet it is structured in such a way and it is only logical to apply the same methodology in describing the world system. Afterall, as the example of the computer system illustrates, a stratified representation is a way to represent a complex system which the system most certainly is, and better understand its behavior.

The basic stratification which we have adopted for our world system model is shown in Fig. 2. On the lowest - geophysical stratum - changes in the physical environment are represented such as e.g. changes in resources, variation in climate, etc. On the second - ecological stratum - the bio-ecological environment is represented, in particular in reference to its relation with man. The next - technological stratum - embodies all of man's activities described in terms of natural laws: energy and mass transfer. The following stratum - economic and demographic - provides description of man's activities not in physical terms but in terms of 'accounting systems' which man has developed traditionally. It should be pointed out that the technological stratum is 'real', while the economic can be viewed as an 'artifact'. Indeed, a proverbial 'visitor from Mars' would readily recognize the technological stratum - e.g. by the amount of dirt being moved around - , but would not identify quite so readily the bank accounts, money flows, and many economic transactions. Yet, for an understanding of the world system behavior the economic stratum is perhaps among the crucial, since it provides the basic motivating force for the changes on the technology and other strata. The next - group stratum -

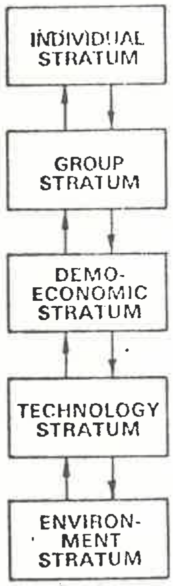


Figure 2 Computerization of the World System Model

embodies various processes and forces governed by and governing the group of people, i.e., the population as such. Finally, the 'stratum of individual' represents the 'common man', its psychological and biological conditions and constraints.

Various aspects of stratification will be discussed later on in this presentation. Also, more specific description on various strata will become clear after more detailed presentations of the model's development. It suffices here, in conclusion, to point out some of its features:

1) Each of the stratum refers to the entire system in terms of space and time and is actually a representation of one and the same real system but from a different angle. In this respect, it is to be contrasted with the earlier mentioned approach in which 'additional sectors' are introduced on what would appear to be the same level in the hierarchy.

2) Stratification depends ultimately on the preferences and biases which one has in viewing different aspects of a complex reality. Our view is anthropocentric, i.e. we are concerned with man's influence on the world system and his fate, and how he shares in the evolution of the system. Ultimately, we hope to help man to chart better his own destiny. This is not necessarily the only view one can take of the world system; indeed that view can be in conflict with a view which emphasizes the global biomass and is motivated by its conservation. A different hierarchy would be constructed for such a study which in turn might very well lead to the conclusion that man is the greatest enemy to biomass conservation - at least under some set of circumstances.

3) Each of the stratum is further subdivided in more substrata depending, again, upon the problem of interest. Also on the same strata many sectorial - i.e. horizontal - subdivisions are made.

3. Regionalization

The major concern in the project is with the global issues; therefore the entire world has to be considered. On the other hand, the prevailing diversity in the world, resulting from history and tradition, will no doubt remain over the period of time we are interested in and indeed might very well be extended in some directions. As a matter of fact, a basic world problem - rapidly approaching crisis proportions - is the inequalities, the so-called gaps, between different parts of the world. For example, it makes no sense whatsoever to talk about average food per capita in the world, when the food is thrown away in some parts of the world while in some others it is in desperately short supply; and the situation, if anything, will worsen under conditions in which the population controlling the food supply consumes the food in an increasingly inefficient way, while the shortage in other parts in continuously rising. The increase in average food per capita in the world as a whole obviously has no meaning in such a situation.

Actually, such a view might do positive harm by misrepresenting the situation: For example, if the food per capita on the world average is sufficiently high, the implication would be that there is no crisis: yet for millions which might be at the starvation level, such a situation represents 'the end of the world' in the most litteral sense. A global uniform or homogeneous representation of the world system is therefore both inaccurate and misleading. Besides, it is useless for the purpose of conflict resolution which should figure among the most important applications for a 'world model'.

The other extreme is to represent the world system in terms of states and nations; such a representation would be unwieldy, not only because of the number of states, but also because of their unequal participation and contribution to the world development.

To acknowledge diversity while preserving unity we have taken a middle road: the world system is represented in terms of regions which through interaction form the world system. No regional arrangements or authority is assumed, but rather the grouping of states to form various regions is done in reference to prevailing socio-economic conditions, tradition, culture and geography, and also in reference to the types of major problems which the states will be confronted with. Namely, we are interested primarily in long-term and crisis-type situations. Those countries which are expected to react similarly to a crisis-type situation are grouped into the same region.

Such considerations lead to the regionalization in Fig. 3. The grouping of the countries into regions is given in Appendix I.

It should be noticed that both higher and lower aggregation is possible. Indeed, we are developing a methodology which will allow the analysis of the long term development of individual countries in the context of the world development. Also, in the process of current studies we are using the following higher aggregations:

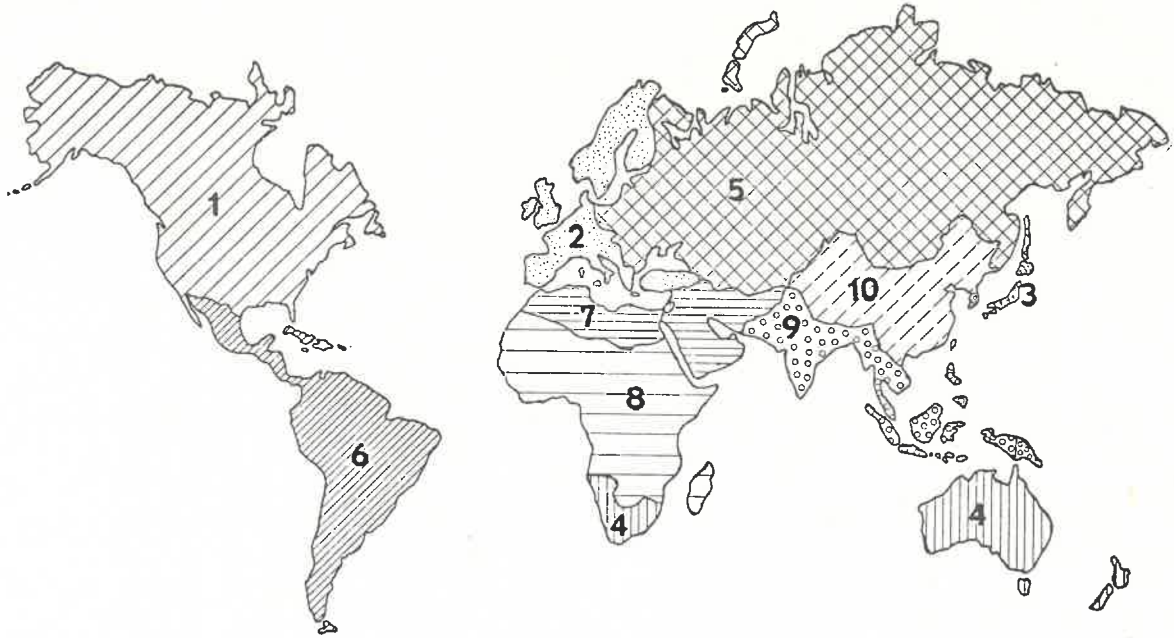


Figure 3 Regionalization of the World System

Four-regions world representation:

Region a - developed world market economies - containing the regions 1, 2, 3 and 4

Region b - centrally planned Europe - which is the same as region 5

Region c - less developed world without China - containing regions 6, 7, 8 and 9

Region d - China - equal to region 10

Three-regions representation:

Region A - developed world - equal to region a

Region B - centrally planned Europe - equal to region b

Region C - less developed world - equal to regions c and d combined

Two-regions representation:

Region I - developed world - equal to regions A and B combined

Region II - less developed world - equal to region C

Finally, we shall also use the combination of regions I and II, i.e., the world as total.

This regionalization as presently used is not necessarily final. For the consideration of certain types of problems the regionalization can be modified. For example, in the consideration of the food supply situation Region 9 will be subdivided in Region 9-i containing Pakistan, India and Bangladesh - and Region 9-ii containing the rest of the region 9.

4. Levels of Resolution and Aggregation

A model for a given stratum - or for a sector within a stratum - can be developed in many different ways and in terms of different degrees of detail. The choice in such a case depends not only on the purpose for which the model is being developed, but also on the existing body of knowledge about the relevant phenomena and the type and amount of data available. Principal distinction between such models is the level of aggregation on which the indicators and variables are used and the degree of resolution in describing the mechanisms and processes involved. We shall first give an example of the resolution levels which we are using in the project and then offer some more general methodological remarks.

Consider e.g. the set of models which were developed for the economic stratum. On the growth level the change of the gross regional product is represented as a function of the achieved or desired growth rate. On the macro level the gross regional product is specified in terms of capital formation and production function, and its distribution given in terms of the main expenditure components. On the micro level the production is specified for various production sectors and intersectoral demands in terms of the input-output matrix. Obviously, each of the models can serve a different purpose and is used accordingly (Fig. 4). At the core is the world economic macro model. It is given in terms of regions interconnected through a trade matrix into a model of the world economic development. The growth indicators which are needed for the growth level model, arc simply derived from the macro model. For each region where the information is available, there is a micro model which is either just a 'satellite of the macro model' or the two interact during the evolution

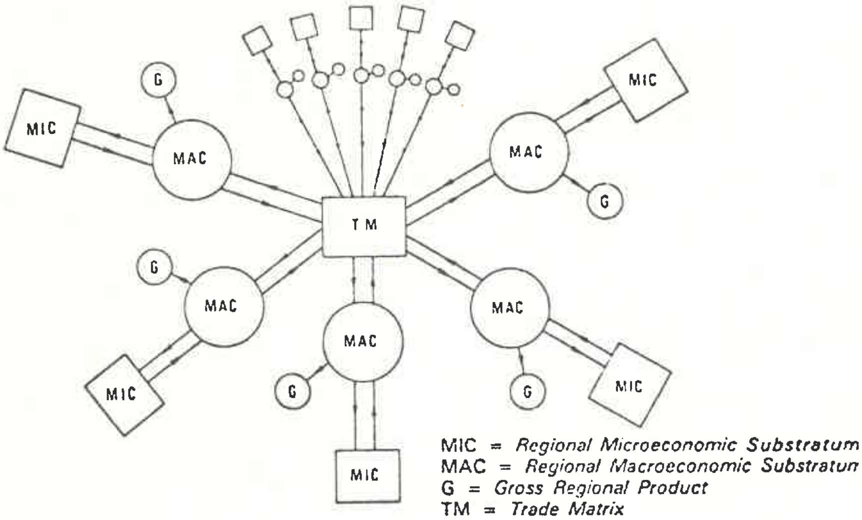

MIC
MAC
G
TM
MIC = Regional Microeconomic Substratum
MAC = Regional Macroeconomic Substratun
G = Gross Regional Product
TM = Trade Matrix

Figure 4

of the system in time. This will be explained further during the presentation of the economic modeling effort. Here let us point out only the advantage of interconnecting the regions on the appropriate resolution level. On the one hand, the interconnections of regions on the growth level would be either constraining or redundant in view of the connections already established on the macro level. On the other hand, the establishment of interregional connections on the micro level even if possible with the data in hand, would introduce tremendous complexity. The trade matrix on the macro level has 100 coefficients specifying the inter- and intra-regional flows. Our data base covers primarily 20 years from 1950 to 1970. To relate the computer trade matrix with the data we were involved in the estimation of 2000 parameters - a formidable job indeed. If we would try to connect the regions on the micro level, and if each region is represented in terms of 9 production sectors, we would have to be concerned with the estimation of several hundred thousand trade parameters. Not only, that this would be unwieldy and impractical but the probability of error would greatly increase while the importance of defect on data would also distort the picture considerably.

The overall structure of our world system development model can be represented in the form of a multidimensional array as shown in Fig. 5.

5. Necessity for Adaptive and Goal-Seeking Representation

The world system is surely an adaptive system exhibiting purposive behavior. After all, history is full of examples where the human society has found new ways to deal successfully with the changing situation. And, humans, the central element in the system, are most certainly pursuing

STRUCTURE OF A REGIONALIZED, MULTILEVEL MODEL OF THE WORLD

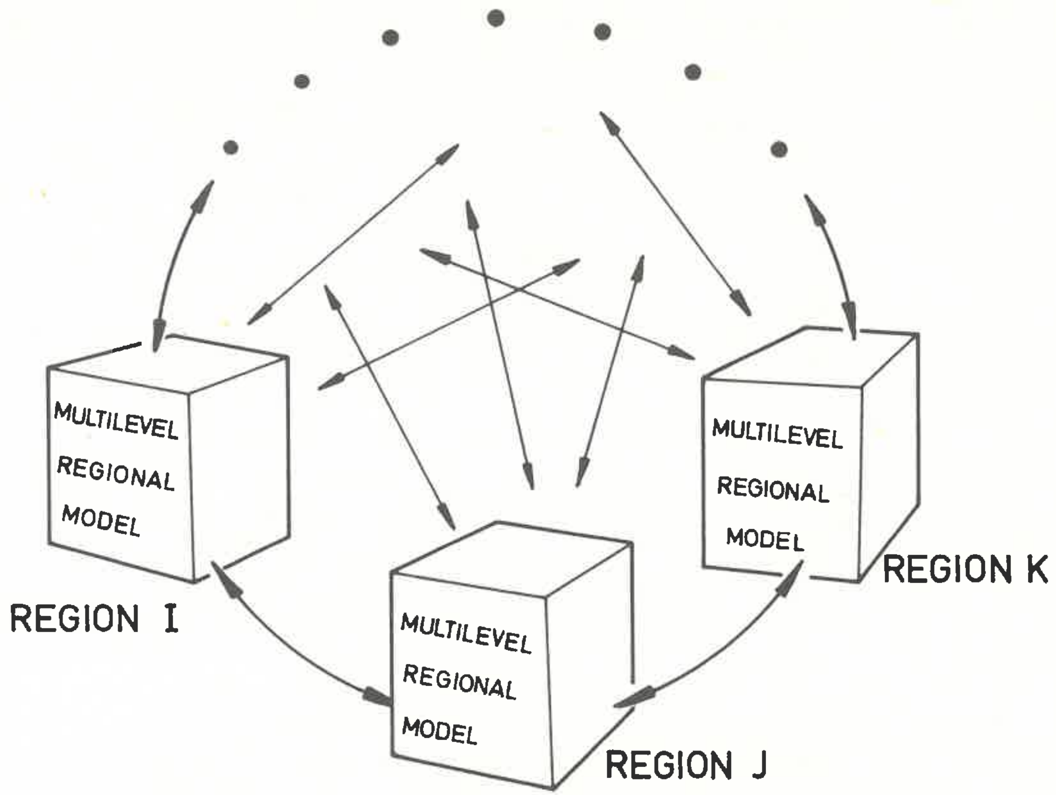


Figure 5

their individual goals. It is clearly essential to account for such crucial characteristics. The formal reasons for representing the goal-seeking or purposive behavior explicitly can be summarized by the following:

If a system is truly goal-seeking, the only effective way to model the system for a sufficiently large set of alternative environmental conditions is to represent explicitly that aspect of the system's behavior.

Let us elaborate some more on that point. A system is in general a set of relationships, experimentally established or assumed to exist, between the observed variables generally classified as inputs (stimuli), and outputs (response). There are two ways how such relationships can be represented. (a) By means of a transformation, which maps inputs into outputs, or more precisely, inputs and (internal) states into outputs; (b) By means of a goal-seeking, purposive or search-'procedure', which in response to any given environmental conditions selects a 'mode' of the system's behavior as most suitable in reference to some internal goals or objectives. In order to describe the behavior of such a system, it is necessary to specify: (i) A set of alternative 'modes' of the system's behavior: (ii) A goal or objective which can be used to discriminate between the alternatives: (iii) A procedure which represents the way the choice is being made in any one of the possible situations.

We can now explain our statement concerning the need for an explicit representation of the purposive or search behavior of the system. Any system, purposive or not, can be viewed as mapping stimuli (inputs) into responses (outputs). After all that is what is clearly observed from outside. However, such a view is of little use, if this transformation cannot be described, e.g., in term of some mathematical equations or algorithms which enable the determination of the output for any given input conditions. And this is the case for purposive systems except in some special 'simple' cases such as e.g., (i) when there exists a 'closed'-form solution for the search problem, i.e. that a fixed strategy can be determined which can be used as the input-output map, or (ii) when the set of environmental conditions is very small, as in the case of controlled laboratory experiments, so that the search-behavior is not exhibited sufficiently strong. The second case surely does not hold in our case. The environmental changes are certainly always present in real life situations. The first case is more subtle but still equally true. Take for example a system whose purposive activity is described in terms of an optimization problem. If the optimization problem has a closed form solution, the so determined optimal strategy specifies the input-output map. But only a handful of optimization problems have a closed form solution; after all, it would be quite surprising if the limited set of functional representations which we possess at present would be sufficient to describe the immense variety and richness of the behavior of purposive systems in nature. As a consequence, if we are concerned only with the behavior of the system in an isolated environment or with systems which have only a single set of inputs, the input-output description is adequate. The more changeable an environment we assume, the less accurate such a representation becomes. Ultimately we have to resort to a purposive, goal-seeking description.

The second reason why the choice-behavior must be represented explicitly is due to the uncertainty how the choice is being exercised. In other words, in real life situations there is, as a rule, a set of alternative courses of actions which are either equally preferable, or appear to be so at the time when the choice must be made. There is no way to ascertain what the choice in such a situation will be. It might actually be determined by the biases which prevail at the time or by pure chance. The analysis of such situations is more direct, if these choices are represented and examined explicitly, rather than 'swept under the rug' by assuming an input-output transformation. Such a reasoning leads to the scenario analysis and on-line conversational mode analysis as we shall discuss later.

Let us now turn more explicitly to the world model under consideration. A major objective of the model-building was to analyze critical - non-routine - events. All routine processes and procedures are represented as input-output procedure. Non-routine responses, however, require a goal-seeking representation, in particular on the higher strata.

This leads to the grouping of the strata as indicated in Fig. 6 into three layers: the norms layer, the decision layer and the causal layer. More on this will be said later.

6. Computer Implementation

The multilevel world system model as presented so far cannot and should not be implemented fully on a computer by means of a closed, self-contained program. Rather, a flexible, open-system modeling, which exploits the interactive and conversational mode of computer analysis must be used. By open-system model we mean a representation in which there is a set of parameters and variables which either are left unspecified or whose values

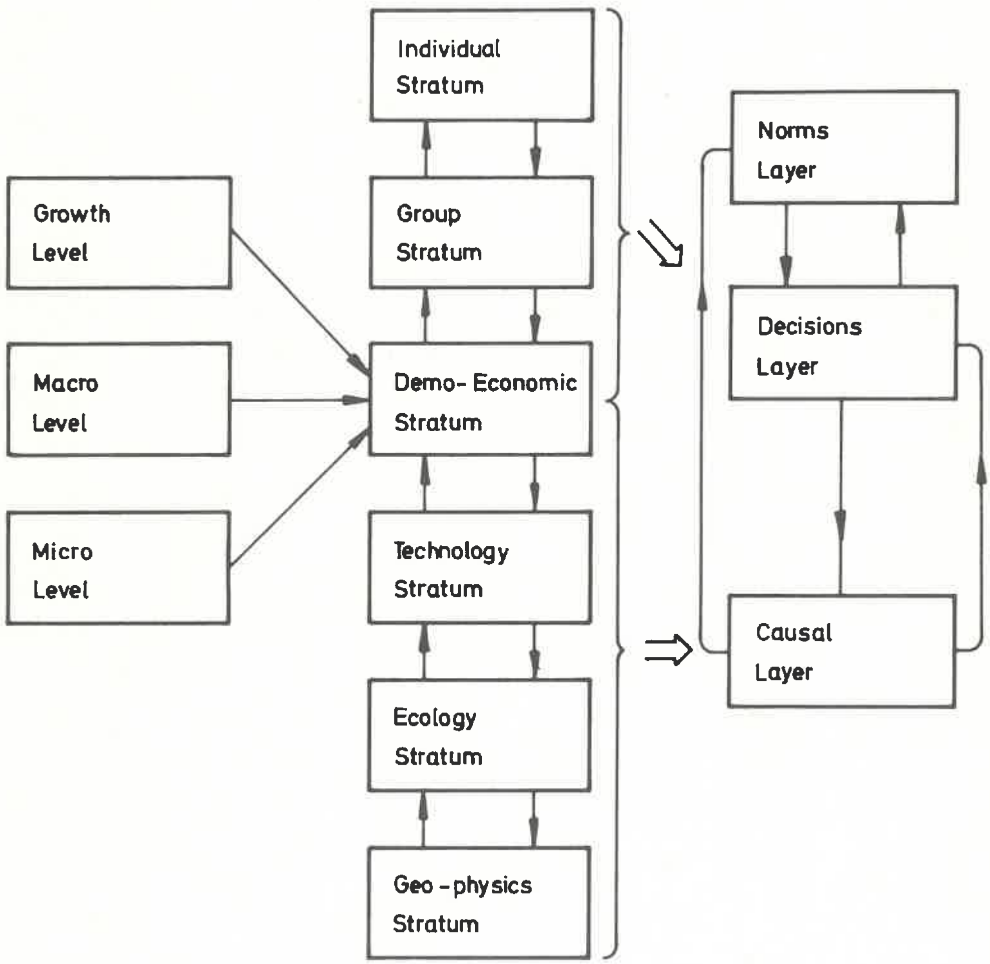

Individual Stratum
Growth Level
Group Stratum
Macro Level
Demo-Economic Stratum
Micro Level
Technology Stratum
Ecology Stratum
Geo-physics Stratum
Norms Layer
Decisions Layer
Causal Layer

Figure 6

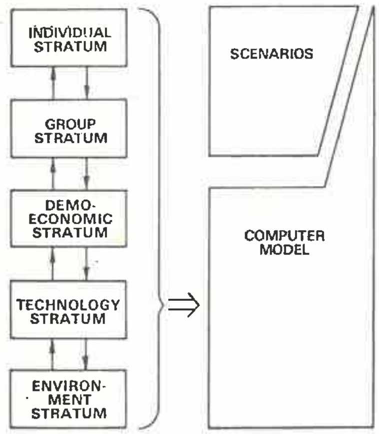


Figure 7 Computerization of the World System Model

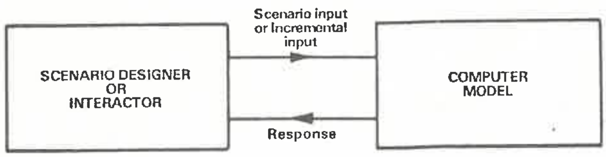


Figure 8 Scenario and Interactive Mode Analysis

are only constrained within certain limits. These variables and parameters reflect the choices to be made by social or political groups which as such will determine the future evolution of the system. The model will not run 'to predict' the future unless these variables are specified. For each different choice of such 'free' variables, from within a given set of alternative choices, there is a different future evolution of the system. Such an open model therefore is not designed 'to predict' the future, but rather to assess the alternative paths of developments. A sequence of such choices which reflects a sequence of possible events determine what we call a scenario. The model therefore is used for the scenario analysis rather than for prediction. The model is thus implemented in two parts (Fig.7): (1) By a computer program which contains all the causal-type relationships, data banks as well as models of decision processes and norms; (2) By designing appropriate scenarios which 'close' the model so as to evolve along a path of a possible future evolution. The division between the computer program and the scenario is indicated in Fig. 7 which will be described more fully in subsequent presentations. To still increase the flexibility in the assessment process and in order to account as much as possible for the element of human judgement, an interactive mode of analysis has also been developed (Fig. 8 and 9) which again will be described more fully later on and will be demonstrated by a link-up with the computer models implemented in Hannover and Grenoble.

Finally, an illustration of the interconnections of submodels on different strata is shown in Fig. 10. This is a most difficult problem in the final construction of the total world system model and the one for which there is least scientific support available. Other illustrations how this problem was solved will be given throughout our presentations.

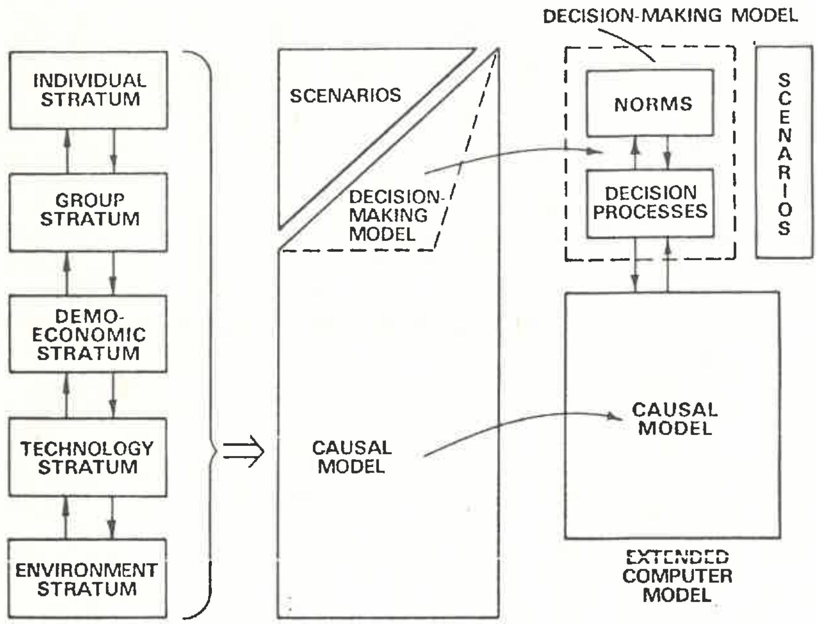
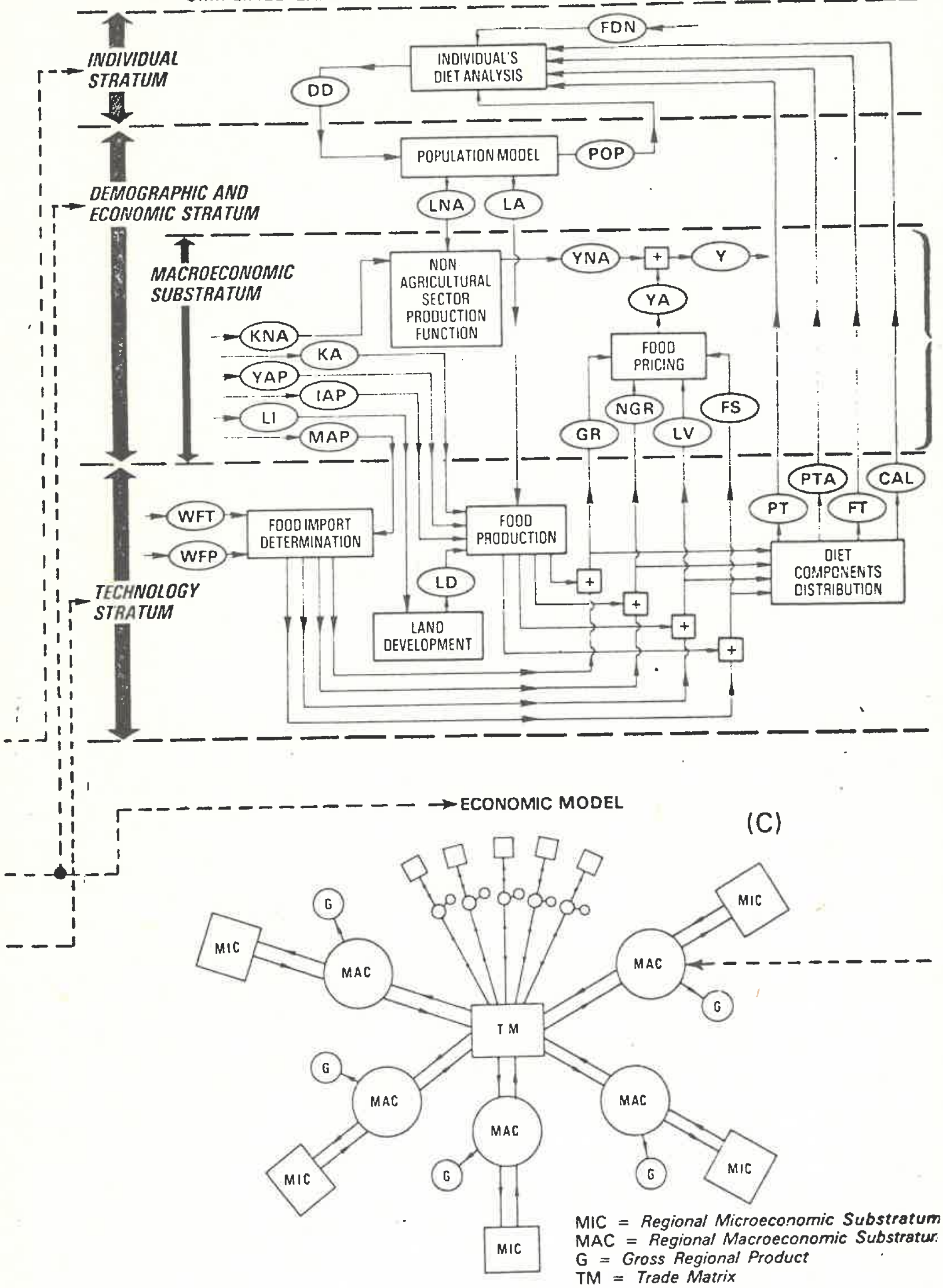


Figure 9 Extended Version of the World System Computer Model

SIMPLIFIED EXAMPLE OF VERTICAL INTERCONNECTION OF STRATA (D)



MIC = *Regional Microeconomic Substratum*
MAC = *Regional Macroeconomic Substratur.*
G = *Gross Regional Product*
TM = *Trade Matrix*

See explanatory captions on following page

Brief on World System Computer Model

The objective of this rather complicated looking diagram is to give an impression for the technically minded reader as to how the computer model is structured and also to provide a glimpse of its real complexity. The reader not interested in the model per se *can safely skip this brief without losing the continuity of the report.*

The model has 10 regions (Figure A) each represented on six different strata (Figure B). The interdependence of all regional models is expressed through appropriate interconnections and exchange mechanisms. For some strata several representations with different degrees of resolution, i.e., different amounts of detail, are used. For instance, on the economic stratum (Figure C) there is a regional macro economic model given in terms of gross regional product, GRP, and major expenditure components: consumption, investment, government expenditure, etc., and also a micro economic model which specifies the economic output and expenditure components in terms of nine production sectors.

An illustration of how different strata are integrated into an overall world system model is shown in Figure D which presents the interconnections between three submodels — population, economics and agricultural production — for the purpose of food supply analysis. Each of these submodels is quite complicated in itself and only some components and variables of key importance for the interconnections are shown in the figure.

The individuals stratum model determines deficiency in diet for individuals (DD) on the basis of population level (POP), the food diet needs (FDN), and food available given in terms of dietary components; protein (PT), animal protein (PTA), calories (CAL) and fats (FT).

The population model determines the population (POP) in various age groups and labor available for agriculture (LA) and non-agriculture (LNA). The population change is influenced by diet deficiency.

For the sake of simplicity only a portion of the economic model dealing with the production functions is shown in the figure and in terms of only two sectors: agriculture and non-agriculture. The production function for the non-agricultural sector is given in purely economic terms, as the so-called Cobb-Douglas type function, with the non-agricultural labor and capital as the inputs (LNA and KNA) and the level of production of the sector (YNA), as the output respectively.

The production function for the agricultural sector, however, is represented in physical terms on the technological stratum because of interest in the assessment of alternative technologies of food production. It has two basic parts: food production and land development. The main inputs come from the rest of the economic model, namely, investment in land development (LI), investment in agricultural production (IAP), allocation of economic output for technical inputs to agriculture — fertilizer, seeds, etc. — (YAP), available capital (KA) and labor (LA). There are two basic outputs: arable land available (LD), and the food produced expressed in ttetrms of grain (GR), non-grain (NG), livestock (LV) and fish (FS). The level of food import (FM) is determined by the economic output allocated for food import (MAF), food available for world trade (WFT) and world food prices (WFP). The total available food in the region is then analyzed in terms of basic diet components and fed back to the individual stratum model. Finally, the economic value of the regional agricultural output (YA) is obtained from the physical quantities produced and the pricing mechanisms. The sum of outputs of all production sectors gives the total economic output, i.e., the gross regional product (Y).

To appreciate the complexity of the model it should be noted not only that each of the boxes in the diagram, e.g., "population model," is in itself a complicated model but also that an analogous structure is given for all regions and that other submodels, such as energy, are also interrelated in a similar fashion.

APPENDIX I

Countries as Grouped in Regions 1 - 10

Region 1. North America

Canada	United States of America

Region 2. Western Europe

Andorra	Italy
Austria	Liechtenstein
Belgium	Luxembourg
Denmark	Malta
Federal Republic of Germany	Monaco
Finland	Netherlands
France	Norway
Great Britain	Portugal
Greece	San Marino
Iceland	Spain
Ireland	Sweden
Switzerland	Yugoslavia
Turkey	

Region 3. Japan

Region 4. Rest of the Developed Market Economies

Australia	Oceania
Israel	South Africa
New Zealand	Tasmania

Region 5. Eastern Europe

Albania
Bulgaria
Czechoslovakia
German Democratic Republic
Hungary
Poland
Rumania
Soviet Union

Region 6. Latin America

Argentina
Barbados
Bolivia
Brazil
British Honduras
Chile
Colombia
Costa Rica
Cuba
Dominican Republic
Ecuador
El Salvador
French Guiana
Guatemala
Guyana
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Paraguay
Peru
Surinam
Trinidad and Tobago
Uruguay
Venezuela

Region 7. North Africa and the Middle East

Abu Dhabi
Aden
Algeria
Bahrain
Cyprus
Dubai
Egypt
Iran
Iraq
Jordan
Kuwait
Lebanon
Libya
Masqat-Oman
Morocco
Qatar
Saudi Arabia
Syria
Trucial Oman
Tunisia
Yemen

Region 8. Main Africa

- Angola
- Burundi
- Cabinda
- Cameroon
- Central African Republic
- Chad
- Dahomey
- Ethiopia
- French Somali Coast
- Gabon
- Gambia
- Ghana
- Guinea
- Ivory Coast
- Kenya
- Liberia
- Malagasy Republic
- Malawi
- Sudan
- Tanzania
- Togo
- Uganda
- Mali
- Mauritania
- Mauritius
- Mozambique
- Niger
- Nigeria
- Portuguese Guinea
- Republic of Congo
- Reunion
- Rhodesia
- Rwanda
- Senegal
- Sierra Leone
- Somalia
- South Africa
- South West Africa
- Spanisch Guinea
- Spanisch Sahara
- Upper Volta
- Zaire
- Zambia

Region 9. South and Southeast Asia

- Afghanistan
- Bangladesh
- Burma
- Cambodia
- Ceylon
- India
- Indonesia
- Laos
- Malaysia
- Nepal
- Pakistan
- Philippines
- South Korea
- South Vietnam
- Taiwan
- Thailand

Region 10. Centrally Planned Asia

Mongolia
North Korea
North Vietnam
People's Republic of China

APPENDIX II

Collaborators and Consultants

B = Braunschweig
C = Cleveland
He = Heidelberg
H = Hannover
K = Karlsruhe
N = Nymwegen
G = Grenoble

The following lists contain the names of scientists actively involved in the construction of the regionalized multilevel world model which is used for the analysis as described in this report, or providing consultation on specific issues regarding the model. The responsibility for the analysis itself, as described in this report and its interpretation, is solely that of the authors.

Directors

Prof. Dr. Mihajlo Mesarovic, Cleveland, USA
Prof. Dr.-Ing. Dr.h.c. Eduard Pestel, Hannover, Germany

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He	Dipl.agr.H.J. Baessler;	food, agricultural ecology
H	Dipl.-Ing. R. Bauerschmidt;	energy resources
C	Mrs. Shelly Baum;	technical preparation
H	Dipl.-Ing. H. Billib;	water resources
K	Dr. H. Bossel;	systems analysis, energy
C	Mr. C. Brewer;	political science
C	Mrs. M.L. Cantini;	technical preparation
C	Mr. N. Chu;	systems analysis

C	Dr. W. Clapham;	food and ecology
K	Dr. R. Denton;	energy
C	Dr. A. Erdilek;	economics
H	Dipl.-Ing. P. Gille;	computer coordination, programming, software
H	Dipl.-Ing. M. Gottwald;	environmental impacts, computer coordination
C	Mr. J. Huerta;	water resources
C	Dr. B. Hughes;	political science, energy
C	Mr. D. Jacobs;	editorial assistance
C	Mrs. J. Kirk;	population
N	Dr. J. Klabbers;	norms, interactive mode
H	Dr. W. Kleeberg;	water resources
H	Mr. H. Kreczik;	illustrations
C	Mr. K. Kominek;	systems analysis and simulation
C	Dr. A. Kuper;	energy
C	Mr. C. Loxley;	economics
H	Dipl.-Ing. H.-H. Maier;	energy
C	Mr. N. Matsuda;	population
C	Dr. M. McCarthy;	economics
C	Mr. A. Mesarovic;	data processing
C	Mr. J. Morris;	data processing
H	Dr. K.H. Oehmen;	population
B	Dr. W. Paul;	population
H	Dr. R. Pestel;	scientific coordination, economics, ecology
G	Dr. F. Rechenmann;	computer science
C	Dr. J. Richardson;	political science
H	Dr. W. Richter;	agriculture
C	Miss M. Schaefer;	technical preparation
C	Mr. T. Shook;	Computer and systems analysis
H	Dipl.Math.a.rer.pol.W. Stroebele;	economics
H	Dipl.rer.pol. M. Szabados;	economics
C	Dr. M. Teraguchi;	ecology
C	Mr.M. Warshaw;	computer science
H	Dr. P. Wiesenthal;	computer science
C	Mr. R. Young;	geology
C	Miss J. Ziffer;	data processing

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Dr. M. Cardenas, Mexico City; water resources
Prof. Dr. U. Colombo, Milan; resources
Prof. Dr. W. Egger, Heidelberg; environment
Prof. Dr. H. Ellenberg, Goettingen; general ecology
Prof. Dr. H. Flohn, Bonn; water resources, climate
Prof. Dr. B. Fritsch, Zurich; economics
Prof. Dr. D. Gabor, London;general studies, energy
Dr. M. Guernier, Paris; agriculture in developing countries
Prof. Dr. B. Hickman, Stanford; economics
Dr. W. Hohn, Hannover: resources
Prof. Dr. J. Hrones, Cleveland: systems
Prof. Dr. L. Huebl, Hannover; economics
Prof. Dr. L. Klein, Philadelphia:economics
Prof. Dr. J. Mermet, Grenoble; computer science
Dr. h.c. G. Sassmannshausen, Hannover; resources
Prof. Dr. P. Schachtschebel, Hannover; agriculture
Prof. Dr. Y. Takahara, Tokyo; multilevel systems
Prof. Dr. F. Ullrich, Goettingen; agriculture ecology
Prof. Dr. J. Wehrmann, Hannover; agriculture

APPENDIX III

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3) Interactive Mode Analysis of Energy Crisis Using Multilevel World Model; Future, August 1973	B. Hughes, P. Gille, R. Pestel, T. Shook, M. Mesarovic A. Erdilek, C. Loxley
4) Simulation of Value-Controlled Decision-Making: Approach and Prototype	H. Bossel, B. Hughes
5) Human Computer Decision-Making: Notes concerning the Interactive Mode	J.H.G. Klabbers
6) Coordination Principles for System Interactions	Y. Takahara

---

* No further bibliography is given, since all references to other relevant literature can be found in our reports.

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11) Specification of Structure for Macro-Economic World Model	B. Hickman, L. Klein, M. Mesarovic
12) Computer Implementation of Macro-Economic World Model	P. Gille, K. Kominek R. Pestel, T. Shook, W. Stroebele
13) Implementation of Micro-Economic Model	T. Shook
14) Cobb-Douglas Production Function for the World Model Project and a One-Sector Growth Model Interpretation	M. McCarthy, G. Shuttic
15) Statistical Analysis of Error Propagation in World Economic Model	G. Blankenship

ENERGY

16) Energy Model: Resources	R. Bauerschmidt, R. Denton, H.-H. Maier
17) Energy Model: Demand	B. Hughes, N. Chu
18) Energy Model: Supply	H. Bossel
19) Regionalized World Liquid Fuels Production and Consumption from 1925-1965	N. Chu

Title	Author
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21) Assessment of the World Oil Crisis Using the Multilevel World Model	B. Hughes, M. Mesarovic, E. Pestel
22) Global Energy Model	R.P. Heyes, R.A. Jerdonek A.B. Kuper
23) Environmental Impact Assessment	M. Gottwald, R. Pestel
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