HIERARCHIAL MODELS OF VERY LARGE PROBLEMS, DILEMMAS, PROSPECTS, AND AN AGENDA FOR THE FUTURE*

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INTRODUCTION

During the past three years, an international group of scholars from many disciplines and from several universities in the United States and Europe has been engaged in developing a set of computer simulation models, focusing on the most critical problems of a global system.[1] The causes of these problems – population growth, environmental stress, and diminishing stocks of nonrenewable resources – are familiar to all of us. Equally familiar are the sorts of oversimplified discussions, ranging from predictions of inevitable doom to simple-minded assertions that no problems exist, which have attracted the widest public attention.

On this subject, where emotion has tended to dominate reason, the Multilevel World Modeling Project represents an application of systems methodology which, in our judgment, is particularly germane to the concerns of this workshop.[2] In this presentation, I should like to discuss the project from an historical and methodological perspective, with particular emphasis of those aspects of our experience which may be relevant to efforts of comparable scope.

THEORETICAL AND METHODOLOGICAL BACKGROUND

Under the direction of Donald P. Echman and, after his death, Mihalo D. Mesarovic, the Systems Research Center of Case Western University has a relatively long history of involvement in this newly developing field, having been concerned with the development of interdisciplinary

*The research described in this paper was conducted in connection with two projects – the Multilevel Regionalized World Modeling Project (conducted at Case Western Reserve University and the Technical University of Hannover, directed by M. D. Mesarovic and Eduard Pestel) and the Phosphorous Pollution Control Project supported by the Rockefeller Foundation.

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[1] The project is under the joint direction of Professor M. D. Mesarovic, Case Western Reserve University, Cleveland, Ohio, and Professor Eduard Pestel, Technical University, Hannover, Germany.

[2] Detailed results were first presented at a four-day meeting held recently (April 29–May 2) in Baden, Austria, under the auspices of the International Institute for Applied Systems Analysis (IIASA). A complete list of the reports presented at that seminar is appended. Copies are available through IIASA.

approaches to the modeling and control of large-scale systems for more than a decade. Of particular importance in this development has been the belief that meaningful application of the systems approach to large-scale problems would be greatly facilitated by the resolution of certain crucial theoretical issues regarding the representation of system structure (refs. 1 and 2).

The results of a number of theoretical papers written during the period from 1961 through 1969 were synthesized and integrated in a major work, "The Theory of Hierarchical Multilevel Systems" (ref. 3). In its first four chapters, this volume lays out a conceptual basis for the study of complex systems, based on hierarchical concepts. Three types of hierarchical structures are distinguished and described formally: levels of abstraction or *strata*, based on different levels of aggregation or complexity; levels of decision complexity or *layers* and levels of priority of action or *echelons*, which are characteristic of the structure of many large organizations. These structural notions are linked to a theory of coordination which is first presented algebraically and, in part II of the volume, using a more classical approach. Here the focus is on real time coordination; however, principles for realizing *satisfactory* as well as *optimal* system performance are discussed.

During the evolution of this body of theory, its generality has been explored through applications in a variety of areas, including organizational behavior (ref. 2), biological systems (ref. 4), artificial intelligence (ref. 5), urban systems (ref. 6), and water resource systems (ref. 7). Thus, the present application of the multilevel approach (refs. 8 and 9) should be regarded as further incremental steps in a lengthy (and continuing) evolutionary process. This process has involved, it should be emphasized, the development of organizational skills that are so essential for the success of large projects as well as technical skills in the application of a particular approach to systems theory. Indeed, the theoretical and organizational elements of the process (and of the present research) have been inextricably linked.

The multilevel approach may be viewed as comprising three principal components:

1. A set of heuristics of decomposing very large complex systems to make them more amenable to formal representation and to provide the basis for developing simulation models.

2. A body of mathematical theory that characterizes large complex systems in detail (more fully developed in ref. 10).

3. A set of methodologies for improving the behavior of complex systems, which includes various coordination strategies and algorithms for achieving, where appropriate, "satisfactory" system behavior as well as optimal system behavior.

During the past four years, the Center has devoted increasing attention to questions of public policy and policy analysis related to two very large systems, the Lake Erie Basin and the world. The goal has been to develop planning and decision-making tools that could be of real value for decision makers. As a consequence of this emphasis, there has been a need to carefully evaluate the tradeoffs between further development of the theory, particularly in the area of multilevel coordination, and the development of models that would be *problem relevant* but not, at least at the outset, analytically tractable.

For a model to be useful to decision makers, it must meet two sets of potentially conflicting criteria that might be labeled (a) comprehensiveness and reliability and (b) usefulness. Included in the first set of criteria are requirements such as

1. Comprehensiveness: The model should incorporate social, economic, and political as well as biophysical and technological variables.

2. State of the art: The model should reflect the state of the art in the respective disciplines primarily concerned with relevant subsystems as well as in system modeling techniques. Although the model is problem oriented, the theoretical paradigms of the respective disciplines should be appropriately taken into account.

3. Problem orientation: The model should focus on the specific problem under consideration and define system boundaries and policy alternatives accordingly.

4. Validity: The model should be able to "predict" the past behavior of the system with a high degree of accuracy. Assumptions and functional relationships in the model should be based on data whose quality meets generally accepted scientific standards of validity and reliability.

To be useful, the following criteria should be met:

1. Simplicity and comprehensibility: The model should be easy to understand, at least conceptually, so that policy makers (or their staffs) who have broad practical experience but are not necessarily familiar with specific scientific disciplines or modeling techniques will be persuaded of its utility and have confidence in its predictions.

2. Client orientation: The model should take into account the goals, values, and points of view of potential users. Moreover, particular care should be directed to ensuring that the goals and values of the modeler are not incorporated.

3. Timeliness: The policy recommendations derived from the model should be available at the time policy decisions are being made.

To date, there have been few systems models developed which focus on broad issues of public policy. Thus there is no consensus regarding the appropriate tradeoffs between these criteria. It is clear that procedures and standards developed in the context of real time systems, or systems where there are excellent data, or systems where there are no time constraints on the development of recommendations will not always be applicable. In the course of the two projects mentioned above, we developed a strategy for constructing multilevel regionalized models of large systems and subjecting them to scenario analysis. It is a strategy, we believe, worthy of consideration.

A MULTILEVEL REGIONALIZED MODEL OF THE LAKE ERIE BASIN

The multilevel regionalized model of the Lake Erie basin was developed in the context of a project with the following broad objectives:

(i) To develop efficient strategies for controlling phosphorus pollution on a regional basis, taking into account economic, societal, and political, as well as public health, scientific, and technological factors, with an awareness of the problems of implementation.

(ii) To develop models needed for these strategies, based on regional inventories and budgets of the distribution of phosphorus using data from, minimally, two regions that markedly contrast with respect to critical ecological, economic, population, and other factors.

(iii) To evaluate alternative strategies for regional control using methods of systems analysis.

The model that evolved is an excellent example of the way in which the multilevel approach provided a conceptual basis that guided the overall research strategy. Initially, five strata were identified and further decomposed into sectors (figs. 1 and 2). While similarities between this structure and the world model may be noted, the inclusion of an institutional regulatory stratum reflected the need to consider a set of normal governmental structures not present in the world system. Several months later, a nine-strata decomposition had leveled, corresponding even more closely to the world model, with the institutional regulatory stratum replaced by a more general institutional stratum (equivalent to the formal organizational stratum in the world model).

Before tracing the further evolution of the model, an additional characteristic of the multilevel approach, of particular importance in this project (but of some importance in the world project as well), should be mentioned.

Quite apart from the philosophic issue of whether multilevel hierarchial structures represent the most valid way to model large-scale systems, the approach is an extremely useful one from the practical standpoint of organizing a model development effort. First, one can draw upon the theories and skills of established disciplines, rather than evoking the hostility of their practitioner as more radically integrated systems modeling approaches often do.[3] Each discipline can be given responsibility for a particular area, while the systems specialist focuses on those problems of synthesis, integration, and coordination he claims are the distinguishing concerns of his own profession. Second, it has been our experience that in large biophysical-social-technological systems, the "state of the art" relevant to the modeling of different strata may be quite different. During the initial phases of the model development process, submodels of the different strata normally develop quite differently. But integrative problems involving boundary definition, level of resolution, and interfacing can often be more easily resolved in terms of the concrete issues posed by well-developed submodels. Third, in the absence of crisis situations, strata have the property of partial decomposability (refs. 15–18). Thus, partial validation of submodels may be possible before the overall model is completely integrated. In crisis situations (the major focus of the Club of Rome Project), the couplings between strata tend to be much stronger (ref. 19).

In the Rockefeller Project, a model development strategy dictated by the above considerations was adopted. Specific subgroups, with commitments to traditional disciplines (ecology, chemical engineering, public health, economics, and political science) were given responsibility for submodel

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[3] The systems dynamics methodology developed by Forrester (refs. 11 and 12) is a prime example of such an approach. Two applications of the methodology by Forrester (ref. 13) and Meadows *et al.* (ref. 14) have evoked considerable hostility.

development. The work of these subgroups provided the basis for the overall integrated model finally developed (refs. 20–22).

Figure 3 shows the structure of the model in its present form. Five strata are modeled explicitly. However, the "softer," higher level strata are only considered by structuring scenarios for analysis. The model focuses on three variables judged to be of critical policy relevance: (a) the number of days during which anoxic conditions in the hypolimnkons of Lake Erie's Central or Eastern Basins, (b) the monthly oxygen depletion rate in the basin hypolimnkons, and (c) the concentration of algal matter in the lake relative to the baseline period of 1950–1973.

Some of the scenarios examined include:

1. Baseline: No pollution control policies implemented after 1973.

2. Advanced waste treatment: Standards for advanced waste treatment specified in the 1973 Water Quality Act, Amendments achieved by 1980.

3. Detergent controls: Controls on the phosphorus content of domestic and industrial detergents implemented by 1980.

4. Regional control: Advanced treatment and detergent controls implemented for the Detroit-St. Clair region only.

5. Advanced waste treatment and detergent controls: Both advanced waste treatment and detergent controls implemented.

Some typical results obtained with the model are depicted in figures 17 and 18.

MULTILEVEL REGIONALIZED WORLD MODELING PROJECT: "PROBLEMATIQUE"[4]

The analysis of problems of a global system poses even more difficult challenges for systems methodology. The cluster of crises with which this project is concerned has been characterized by the Club of Rome as the "world problematique" to draw attention to the uniqueness and magnitude of the problems involved and to the extreme difficulty encountered in understanding the evolving situation, not to mention finding a remedy and the means to avoid disaster. In our judgment, they differ in several significant respects from other events in world history.

First, *the problems are global*: for some of the problems, for example, the energy crisis, this is quite obvious. For others, such as the threat of starvation in particular regions, the global character is felt either through sociopolitical or economic interdependence. The global character of the problems makes them very difficult to solve from the perspective of national or even regional institutions which have, more often than not, conflicting concerns.

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[4] This discussion of the "problematique" is based on the remarks of Professor Pestel to the IIASA Symposium.

Second, *the changes are felt through the entire society.* Economic, technological, environmental, sociopolitical, and many other aspects appear to interact in such a way that what might appear to be a desirable strategy in one domain makes the situation only worse in others. This hinders the solutions of problems by traditional means which reflect only the concerns of a single discipline or domain (e.g., technology, economics, ecology, or the specialized fields of engineering).

Third, *there is a conflict between short- and long-range actions and goals.* A short-range solution often only compounds the long-range problem, making it worse when it reappears.

Fourth, *there are considerable delays between the time when a corrective action is applied and when its remedial effects are felt.* For example, a successful population-control policy aimed at achieving an equilibrium level of population will take 30 to 50 years and possibly more before the goal is reached.

Finally, in contrast with past crises, *the crises of the world problematique appear to result from actions that have been traditionally considered desirable*: to have a large family, to use as much energy as possible to save human labor, or to exploit nature to the utmost for the benefit of man. Thus, solutions must involve changes in values that have been traditionally considered sacrosanct.

For many, especially in Europe, the problematique first became a matter of attention and concern through Dennis and Dana Meadows' compelling and controversial book, *The Limits to Growth* (ref. 14), which reported on the results of the first "world modeling" project (initiated under the auspices of the Club of Rome). This project was based on the *systems dynamics* methodology, first developed by Professor Forrester at M.I.T. during the early 1950's.

Because of the wide familiarity with the "World I" and "World II" models of Forrester and Meadows, it will be useful to illustrate some significant characteristics of the multilevel approach by contrasting the major theses of the M.I.T. project with those of this project.

The theses of the M.I.T. project are roughly summarized as follows:

1. The world can be viewed as one system.

2. The system will "collapse" sometime in the middle of the next century.

3. To prevent collapse, an immediate slowdown of economic growth must be initiated, leading to no growth in a relatively short period of time.

By contrast, the most significant theses of the Regionalized Multilevel World Modeling Project are:

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 a collapse of the world system as such, catastrophies or collapses on a regional level may occur (and, in the absence of positive remedial policies, *will* occur), possibly even long

before the middle of the next century, but 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 a global context and by appropriate global actions. If the framework for joint action is not developed, none of the regions will be able to avoid the consequences. For each region, its turn will come in due time.

4. Such a global solution can be implemented only through selective and balanced growth, not uniform, but greatly differentiated and diversified 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 or costly, but deadly. What we are truly talking about is a "strategy for survival."

A STRATIFIED MODEL OF INTERACTING REGIONS IN A WORLD SYSTEM[5]

The original conception for the world model was published by Professors Mesarovic and Pestel in early 1972. The model has two principal and unique features, a *multilevel, multigoal structure and regionalization*. For each regional submodel, three general strata – the *norms stratum, organizational stratum, and causal stratum* – are identified. In addition, there are eight more specific strata. This structure (fig. 6) provides general guidelines for developing more specific problem-oriented models such as those focusing on food and energy problems.

The basic level of the models is the "causal stratum" containing elements such as the economy, resource levels, population dynamics, and technology developments. The causal stratum is designed to reflect the basic operation of model variables in areas where there is relatively little governmental intervention. The approach to modeling phenomena in this strata conforms closely to work of established discipline in the scientific community.

Because governments do, of course, often intervene to resolve (or at least attempt to resolve) pollution problems, overpopulation, energy shortages, and the like, these phenomena are incorporated in an organizational or institutional stratum. Thus the model is conceived as a true cybernetic control system with the organizational stratum attempting to maintain relative equilibrium within the causal stratum. In some of the models developed for the project, these phenomena were simulated. For example, Hughes (refs. 24 and 25) developed a model of crisis decision making in the energy sector (fig. 7). In other models, human interactors were used to provide the inputs from the organizational stratum to the causal stratum (fig. 8). In analyzing decision processes to incorporate them into the models, the concept of *multilayer*, hierarchical decomposition is often used.

The final layer of the model (in each region) is the normative stratum. In addition to the factors that influence decision making represented in the organizational stratum, decisions are also

[5] The discussion in this section owes a great deal to an excellent report by our colleague Barry B. Hughes (ref. 23).

shaped by the social values and other beliefs of decision makers. These determine, in large part, the final selection of a policy from a set of generally acceptable or satisfactory policies. The elements in this third stratum quite obviously pose the greatest difficulties for any attempt to completely simulate policy making. An alternative is to allow actual decision makers or other model users to introduce their own norms through interaction with the computer model.

Regionalization

The model has been subdivided into "regions" or groupings of countries similar with respect to the major political and economic variables of the model. That is, nations within a region are at approximately the same stage of economic development and share similar political structures. Regions need not be geographically contiguous. As noted above, regionalization is important because of major differences between the initial levels of major model variables (especially the gap between the rich and the poor) and in probable development patterns. In addition, the available and desirable policies in different regions may be quite different. Regions are interconnected via trade flows, population migrations, and other movements across regional boundaries.

Ten regions have been established since the research model building began: North America, Western Europe, Japan, Rest of the Developed World, Eastern Europe, Latin America, Middle East, Main Africa, South Asia and China (fig. 9).

APPLICATION OF THE MODEL TO THE WORLD FOOD CRISIS IN SOUTH ASIA

To gain a clearer understanding of the way in which the general principles and structures discussed above are actually implemented, it will be useful to discuss a more detailed analysis of a specific problem. From the overall set it submodels, a model that focuses on world food problems (called the Integrated Food Policy Analysis Model) has been developed. Unfortunately, the description of even this segment of the project cannot be very detailed. The complete model includes six major submodels and its detailed documentation runs to two volumes, each roughly the size of a telephone directory for an urban center of moderate size (ref. 26, 27).

Four of the major components of the food model – population submodel, economic submodel, land use submodel, and food production submodel – were developed, programmed, and validated individually before integration. The interrelationship between these components is shown in figure 10. Figure 11 is a more detailed representation. Two submodels were developed in Cleveland, one in Hannover and one jointly in Hannover and Cleveland.

Major Submodels

The *population submodel* was developed by K. H. Oehman and W. Paul of the Technical University, Hannover, under Dr. Pestel's direction (ref. 28). To present a highly resolved picture of demographic phenomena, the total population of each region is divided into 86 age groups. For each group, age specific fertility/mortality rates are defined as probability distributions. Regional immigration and emigration are also defined on an age specific basis. Population distributions, fertility, mortality, and immigration patterns are sensitive to regional differences.

The *economic submodel* is a two-sector microeconomic model aggregated from a nine-sector model developed by M. D. Mesarovic, L. Klein (University of Pennsylvania), B. Hickman (Stanford University), T. Shook (Case Western Reserve), and P. Gille (Technical University, Hannover). The nine-sector model was based on a regionalized macroeconomic model developed by M. D. Mesarovic and K. Kominek (Case Western Reserve). The model provides an excellent example of the way in which detailed models of particular strata are modified to focus on specific problem areas in integrated models. For the nonfood sector, the production function is derived from the sectoral Cobb-Douglas production functions of the microeconomic model. There is no direct coupling to lower strata. However, the production function for the agricultural sector is based on linkages with the land use and food production submodels. Since variables in these submodels are in physical units rather than dollars, the strata must be coupled through a pricing mechanism that specifies dollar values for commodities and other factors of production. Prices are sensitive to scarcity of land, computed within the model, and to factors such as energy shortages through manipulation, of scenario variables.

In the *land use submodel*, six categories of land – cultivable but uncultivated, grazing, developed, cultivated grain, cultivated nongrain, and fish pond are defined. The rate of increase in cultivated land is determined by the amount of investment in land development and land development costs (which are affected by the market value of land). As population increases, the land is withdrawn from agricultural uses for urban and economic development.

Because the food production submodel computes information on 26 food types, it appears to be quite complex. The fairly high level of disaggregation permits an examination of the different uses of foodstuffs in different regions and allows for cost estimates of future dietary patterns in concrete terms. But the underlying rationale of the model is straightforward. Gross production levels in the three sectors – plants, livestock, and fish – are determined by the input level of land, capital, and other factors of production. Production levels for the various food types are determined by gross production levels with adjustments made for the utilization of some portion of the output for seed and livestock. In calculating the net food production level from which regional production of calories and protein is computed, household, marketing, and food processing losses are also considered. Protein and calories produced in the food production sector, along with imports (if any) are inputs to the population model. Both the land use model and food model were developed by P. Clapham and M. Warshaw (Case Western Reserve).

Scenario Analysis of the Food Crisis in South Asia

A detailed discussion of the scenario analysis completed to date is beyond the scope of this paper (see refs. 20 and 24). However, for illustrative purposes, some of the results from four scenarios, focusing on the capability of the South Asia region to implement "self-help" policies, are presented in figure 12. Descriptive titles of the scenarios are (1) *baseline*, a projection of historical trends; (2) *agrarian development*, an attempt to produce more food by shifting investment to the agricultural sector; (3) *population control*, a policy designed to limit births and gradually achieve a state of equilibrium over a 70-year period; and (4) *population control and agrarian development*, implementation of both (2) and (3).

AN AGENDA FOR THE FUTURE

As we approach the last quarter of this century, specialists in systems theory and methodology are proposing applications of their expertise to a growing number of economic, social, and political problems. Since the root of many problems facing contemporary society appears to be man's inability to manage the large, complex systems he has, at least in part, created, it is hoped that this new contribution will be significant. A framework for such applications and two specific examples were discussed in this paper.

Determining future research need has been defined as one of the principal objectives of this seminar. In this concluding section, I should like to reflect rather broadly on this issue, drawing from but not limiting myself to the areas that have already been discussed. This reflection takes the form of rather specific recommendations in three broad areas:

1. The development of more broadly focused, integrated systems models.

2. Resolution of certain technical problems that presently limit the application of systems models to broad issues involving public policy.

3. Creation of a receptive attitude on the part of decision makers to the kinds of issues raised by such models and to the proposed solutions.

Development of More Broadly Focused Integrated Models

In cooperation with social scientists, philosophers, and humanists, systems specialists should devote major attention to sharpening the way in which important issues involving public policy and human values are defined. The task of exploring such issues should be recognized as an integral and crucial part of the modeling process.

To date, systems specialists have shied away from attempts to incorporate the "soft" variables that are the concern of social scientists humanists as an integral component of their models. Those undertaking such attempts have been severely criticized and, in many instances, the criticism has been justified. Given the "state of the art" in the social sciences and humanities, it is not surprising that this should be the case. But "softness" of a particular variable or phenomena does not justify its exclusion from consideration (ref. 22). If a truly cooperative relationship can be developed between systems specialists, social scientists, and value-oriented scholars, the latter may become more sensitive to the precision that systems models require. At the same time, systems specialists will be compelled, through their deeper understanding of "soft" phenomena and value issues, to develop new structures to accommodate them.[6]

In training systems specialists, skill in judgment and in design, rather than purely mathematical computational skills, must be emphasized.

[6] A particularly intriguing approach to this problem has recently been proposed by Bossel and Hughes (ref. 29).

Throughout this paper, the role of heuristic skills and the need for judgment in developing broadly focused systems models has been emphasized. The skills in applying systems methodology to new areas will not be sharpened by a repetitious examination and marginal modification of existing techniques and models. Instead, students must direct greater attention to a broad spectrum of cases involving successful application to new areas, focusing, in particular, on the design process in model development.[7]

The development of an organizing framework for integrated models must be a high priority objective.

During the past 10 years (as noted above), Mihajlo Mesarovic and his associates, including the author, have demonstrated the applicability of the multilevel approach to a variety of subject matter areas and have argued vigorously for its adoption as an organizing framework for systems modeling. Our proposal can be divided into three parts: (1) demonstration of the need for *some* organizing framework, (2) specification of criteria that *any* framework must meet, and (3) presentation of a specific framework, the multilevel approach, which meets the demonstrated need and conforms to the specified criteria. Until recently, however, even the need for such a framework has not been a major concern. Thus, it has been difficult to develop a frame of discourse in which the claims of the multilevel approach could be evaluated. We believe that the kinds of concerns to which the multilevel approach has responded should be regarded as more critical and central in systems theory and methodology.

Within the limits of their capabilities, systems specialists should attempt to promote a more favorable institutional environment for the cooperative enterprises necessary to develop integrated models.

In the United States, at least, much of the intellectual talent that must be mobilized to develop large integrated models is found in private and public universities. But it is difficult to conceive of an institution less suited to the kind of broadly focused cooperative effort this developmental process entails. A study in which the author participated identified similar problems in many Asian, European, and Latin American universities (refs. 31 and 32). Systems specialists cannot and should not be expected to resolve the problems of defensiveness, parochialism, and fragmentation which have plagued academic and research institutions since the time of Plato's Academy. But they can, at least, be especially sensitive to these problems when defining the boundaries of their own activities. Where appropriate and feasible, they should also work to strike down the impediments to cooperative research in the institutions of which they are a part.

Development of More Technically Sound Integrated Models

Major attention should be devoted to defining data requirements and encouraging necessary data-collection efforts to support the development of broad based integrated models.

Lack of adequate data poses a serious impediment to the development of broad-based models, expecially in the areas of social, institutional, and political phenomena. Even where data seem

[7] A program that reflects many of the same objectives has been presented in greater detail by Simon (ref. 30).

plentiful, they are often the wrong data. Existing data base structures necessarily have embedded within them the criteria of relevance germane to the eras and institutions that fostered their development. These criteria are often partly, or wholly, inconsistent with the requirements of contemporary systems modeling methodologies. One is often faced with the problem of developing what seems to be an accurate model structure for which little or no data are available, or developing a somewhat inaccurate model to fit the data available. The development of new models and supporting data bases are necessarily two sides of the same coin and must be recognized as such.

In cooperation with mathematicians and statisticians, systems specialists must direct attention to the development of new parameter estimation procedures appropriate for broad-based integrated models.

Related to the data problem is the problem of developing appropriate parameter estimation procedures where data are incomplete, but the model structure and problem require the inclusion of a theoretically significant variable. While existing estimation procedures in econometrics, operations research, statistics, and engineering are a useful starting point, it should be recognized that they have been devised to meet a quite different set of problems from those that may be encountered in the future. Again, this is especially true where social and institutional phenomena are the object of concern or where the time horizon of the model is measured in decades.

In cooperation with philosophers of science, statisticians, and mathematicians, systems specialists should develop more appropriate validation procedures for broad-based integrated models, especially those involving long-term forecasting.

Many of the models being developed purport to make policy-relevant predictions about events that will occur 10, 20, or even 50 years in the future. What kinds of legitimate statements can be made to decision makers regarding the probability that a particular prediction or scenario is, in some sense, valid? Presently, a degree of validity is claimed for models if they "fit" historical data. But it is by no means certain that this approach to validation is sufficient given the fact that both parameter and structural changes may be imposed on a model to explore a particular set of alternatives. It may well be that a fundamentally different approach[8] from that presently available will be required to deal with the validation of these models.

Development of a Receptive Attitude on the Part of Decision Makers toward Recommendations Based on Systems Models

The claims made for the usefulness of systems models should not exceed a conservative assessment of their actual utility.

For broad-based integrated models to achieve the potential envisioned by their advocates, considerable progress must be made in resolving the technical problems discussed previously. Model builders must be able to offer confidently the recommendations based on their models and decision makers must be able to accept them with equal confidence. Nothing could be more harmful than

[8] "Fundamentally different approach" is used in the sense suggested by Kuhn (ref. 33).

for systems specialists to persuade decision makers to accept their recommendations in a new area before they have meaningful recommendations to give.

A concern with long-term, broadly defined goals must become institutionalized, preferably within existing local, state, and national governments.

In the United States, at least, there are few individuals at any level of government who think in concrete terms beyond the next election. Given the existing structure of many political institutions, this is often rational behavior. In view of this, perhaps new structures will be needed to accommodate these kinds of goals and objectives. Should this be true, politically oriented systems engineers should be able to play an active role in designing such structures.

A CONCLUDING THOUGHT

One of the major problems facing the systems field profession may be broadly defined as the problem of technology transfer – both to potential users and to other professions whose assistance is crucial to the development of broad-based integrated models. For several years, the author devoted considerable attention to the problem of transfering American agricultural technology to Asia, Africa, and Latin America. There are at least two lessons learned from that experience which may be of some relevance.

First is the importance of a "demonstration effect." A demonstration effect is an event – often fortuitous – which provides concrete, highly visible evidence that the new technology could solve a particular problem that has been of major concern to the community. Substantial evidence exists that such an event is a necessary, though not a sufficient, condition for technology transfer.

The second lesson is the importance of communication, and the complexity of the interface between specialists developing a new technology and the client groups they are attempting to serve. In the United States, the farmer is two steps away – via extension agents and experiment stations – from academic agriculturalists in universities. We found that similar "interface" mechanisms adapted to potential recipient cultures were essential to the process of technology transfer, innovation, and change. While the analogy to problems faced by contemporary systems specialists may not be straightforward, they should recognize that a serious communication problem presently exists. Moreover, it is the systems specialist who must adapt to the attitudes and perceptions of potential clients rather than the reverse. In the long run, solving the communication problem may be more important and more difficult than any discussed previously.

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FURTHER READING

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Methodology	
1. Objectives, Motivation and Conceptual Foundations	M. Mesarovic, E. Pestel
2. A Goal Seeking and Regionalized Model for Analysis of Critical World Relationships – The Conceptual Foundation, Kybernetes Journal, 1972	M. Mesarovic, E. Pestel
3. Interactive Mode Analysis of Energy Crisis Using Multilevel World Model; Futures, August 1973	B. Hughes, P. Gille R. Pestel, T. Shook M. Mesarovic
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
7. Conversational Use of Multi-Layer Decision Models	F. Rechenmann
8. PROMETHEE (Programmed support for models of Earth Trends, Hierarchical, Economic, Ecologic)	J. Mermet
Population	
9. Population Model, Vol. I and II	K. H. Oehmen, W. Paul
Economics	
10. Methodology for Construction of World Economic Model	M. Mesarovic, E. Pestel
11. Specification of Structure for a 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

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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
20.	A Description of the World Oil Model	B. Hughes
21.	Assessment of the World Oil Crisis Using the Multi-Level 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

Food

24.	A Regionalized Food Model for the Global System	W. B. Clapham, Jr. M. Warshaw
25.	The Integrated Food Policy Analysis Model: Structural Description and Sensitivity Analysis	M. Mesarovic J. M. Richardson, Jr. M. Warshaw
26.	Scenario Analysis of the World Food Problem, 1974–2025, Using the Integrated Food Policy Analysis Model	W. B. Clapham, Jr. M. Mesarovic J. M. Richardson, Jr. M. Warshaw
27.	A Model for the Relationship between Selected Nutritional Variables and Excess Mortality in Populations	T. Weisman

Water Resources

28.	Water Resources Model	M. Cardenas

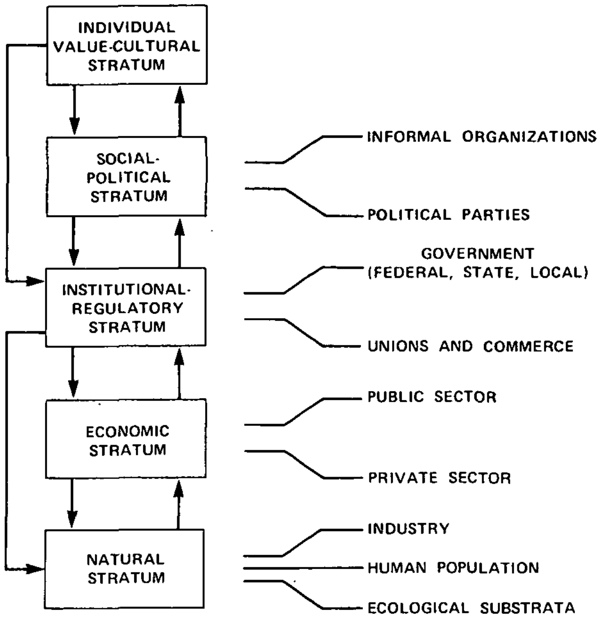
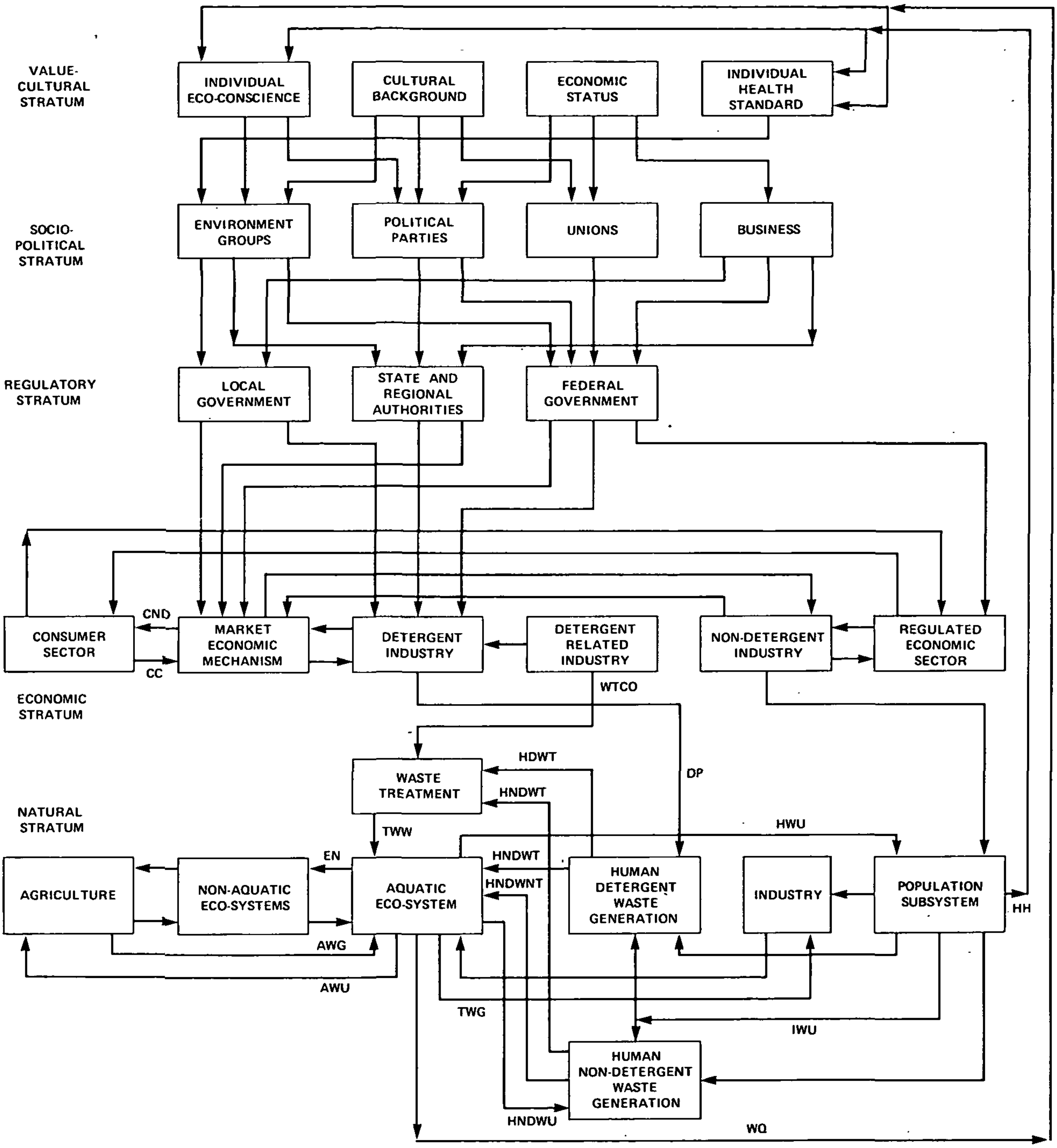


Figure 1.–Initial stratified decomposition of phosphorus management model.



HDWT – HUMAN DETERGENT WASTE TREATED
HNDWT – HUMAN NON-DETERGENT WASTE TREATED
HDWNT – HUMAN DETERGENT WASTE NOT TREATED
HNDWNT – HUMAN NON-DETERGENT WASTE NOT TREATED
HNDWU – HUMAN NON-DETERGENT WATER USE
HWU – HUMAN WATER USE
WQ – WATER QUALITY
HH – HUMAN HEALTH

AWU – AGRICULTURE WATER USE
AWG – AGRICULTURE WASTE GENERATION
TWW – TREATED WASTE WATER
IWU – INDUSTRY WATER USE
DP – DETERGENTS PRODUCED
CND – CONSUMER NEED IN DETERGENTS
WTCO – WATER TREATMENT

Figure 2.–Sector decomposition of phosphorus management model.

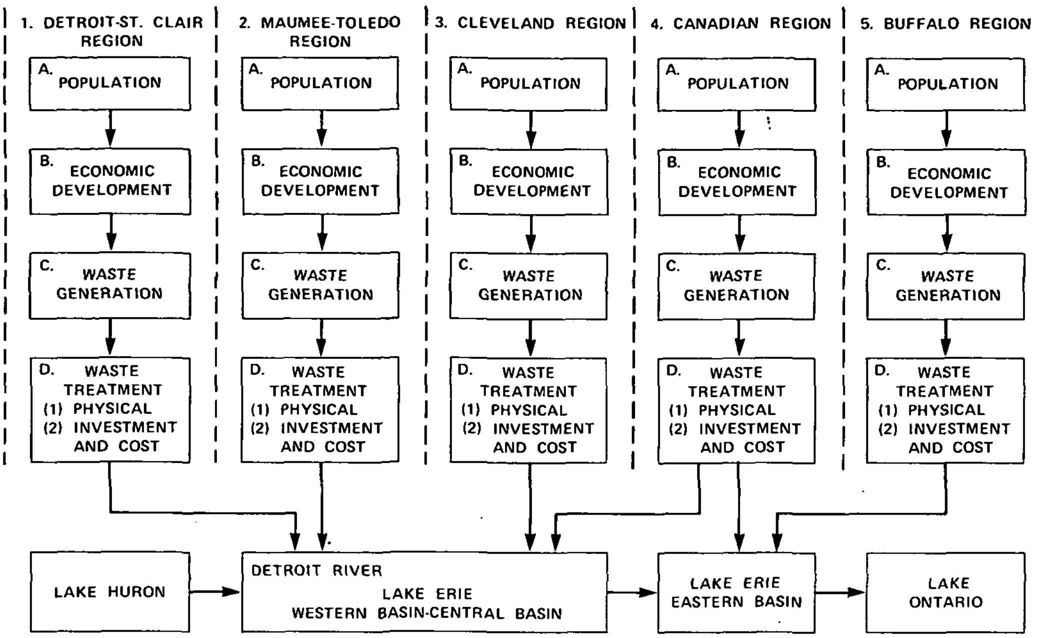


Figure 3.–Integrated model for interactive scenario analysis.

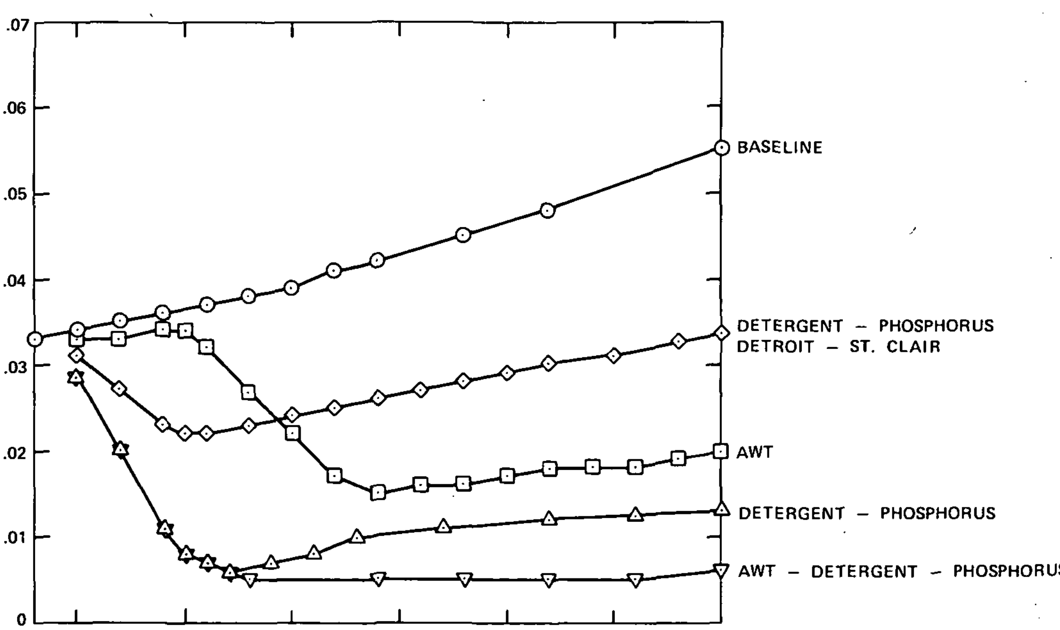


Figure 4.–Dissolved phosphorus concentration (DPC) central basin.

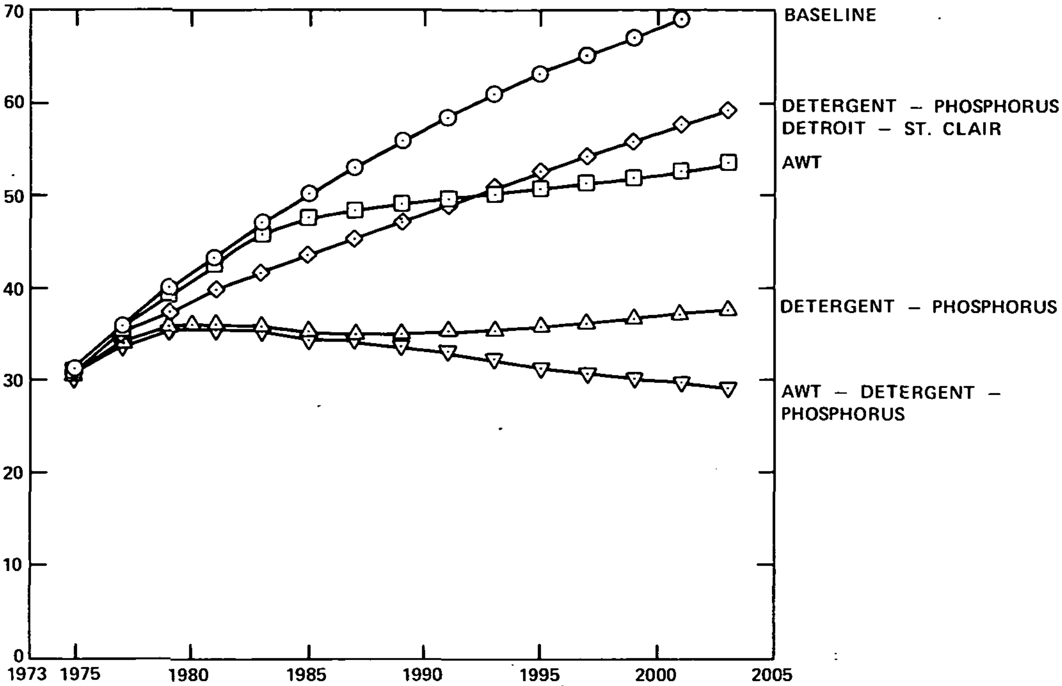


Figure 5.–Days of anoxia (DOA) central basin.

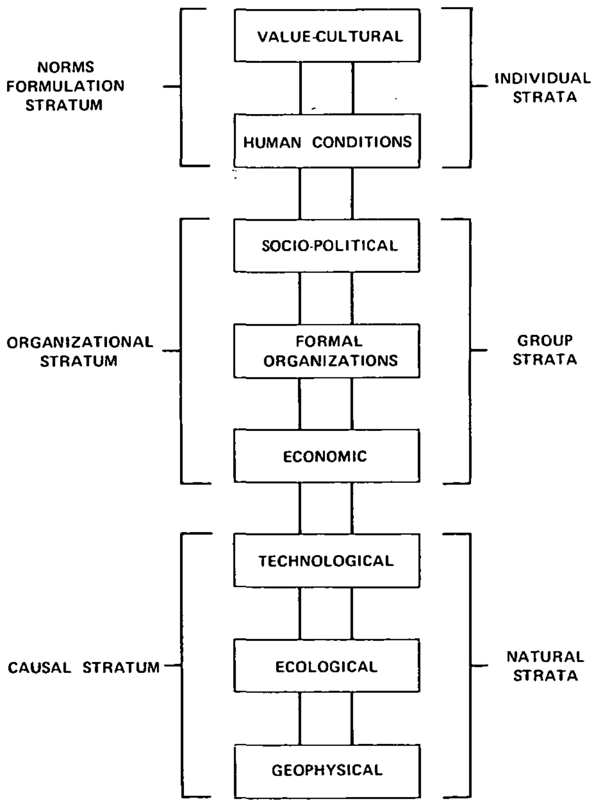


Figure 6.–General stratum for regional submodel.

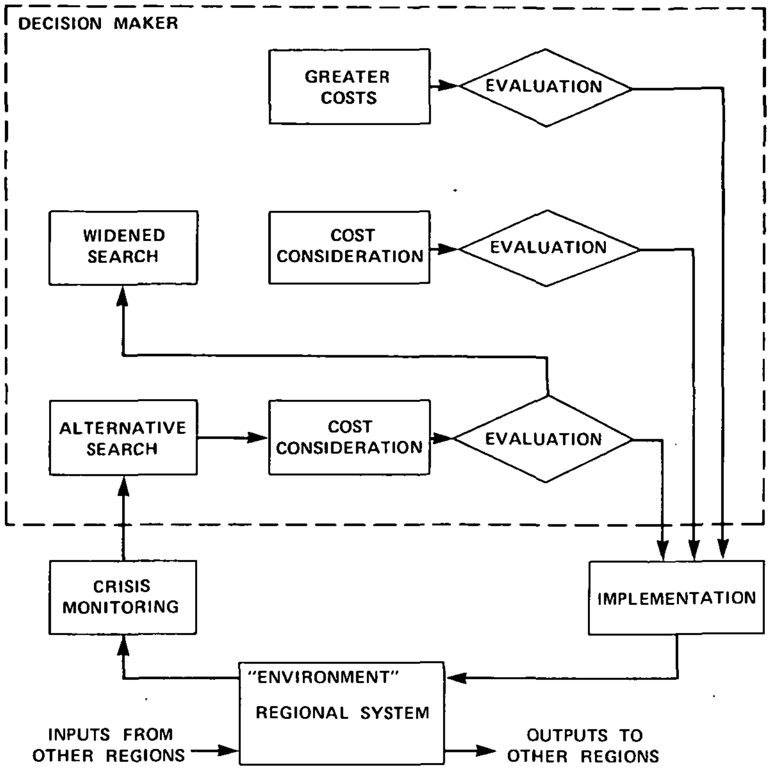


Figure 7.–Basic components of the Hughes crisis decision-making model*
*Adapted from Hughes (ref. 23)

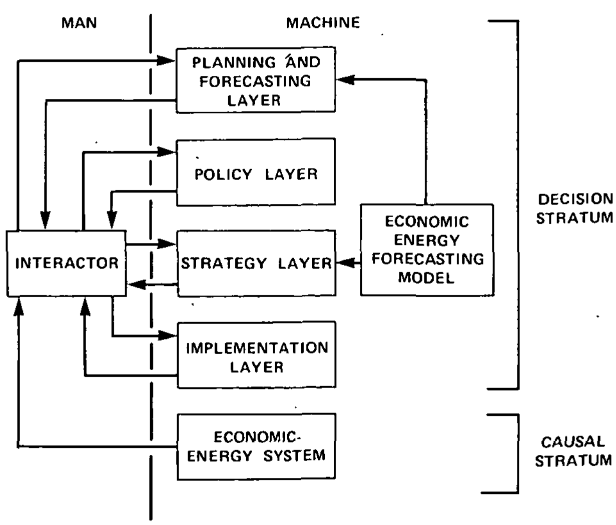


Figure 8.–Model with human interaction.

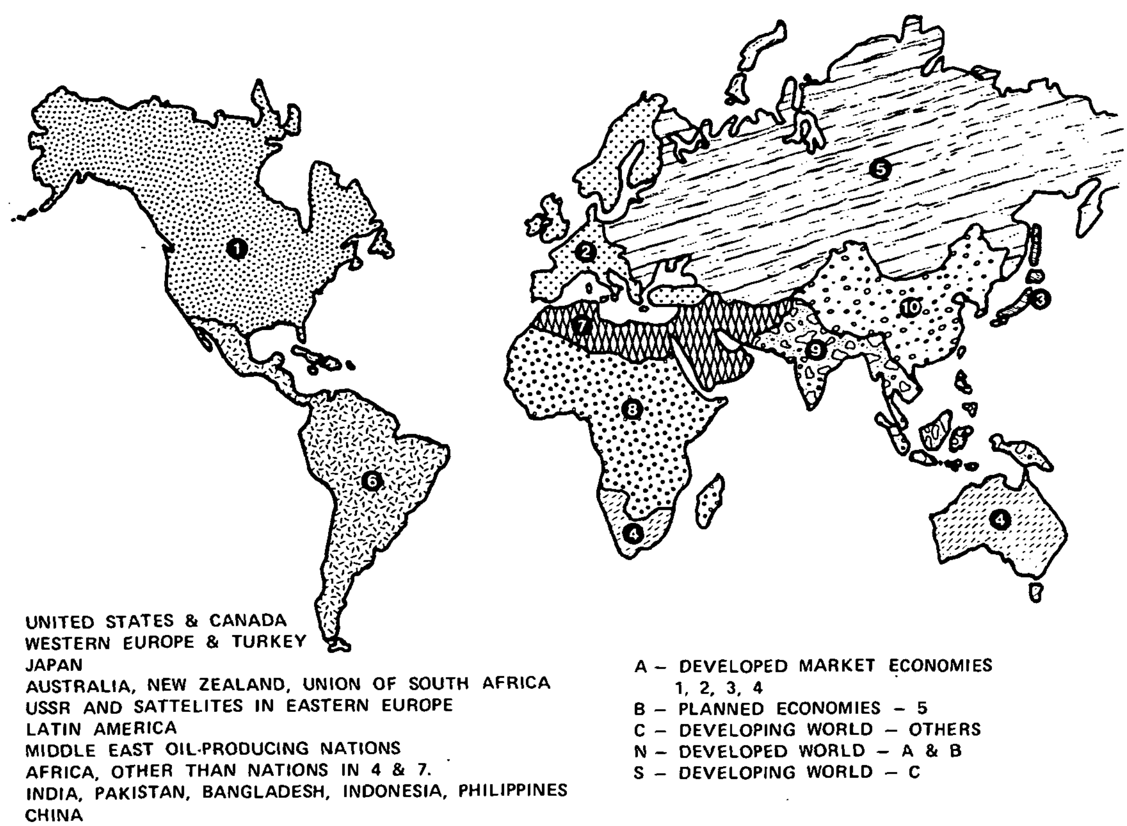


Figure 9.–Regionalization

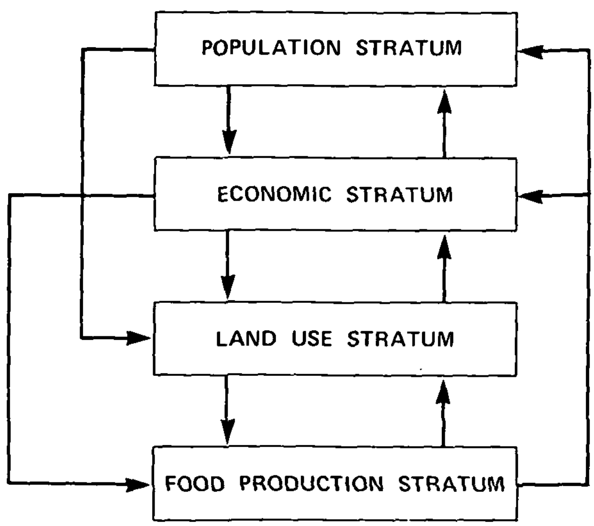


Figure 10.–Integrated food: policy analysis model basic strata.

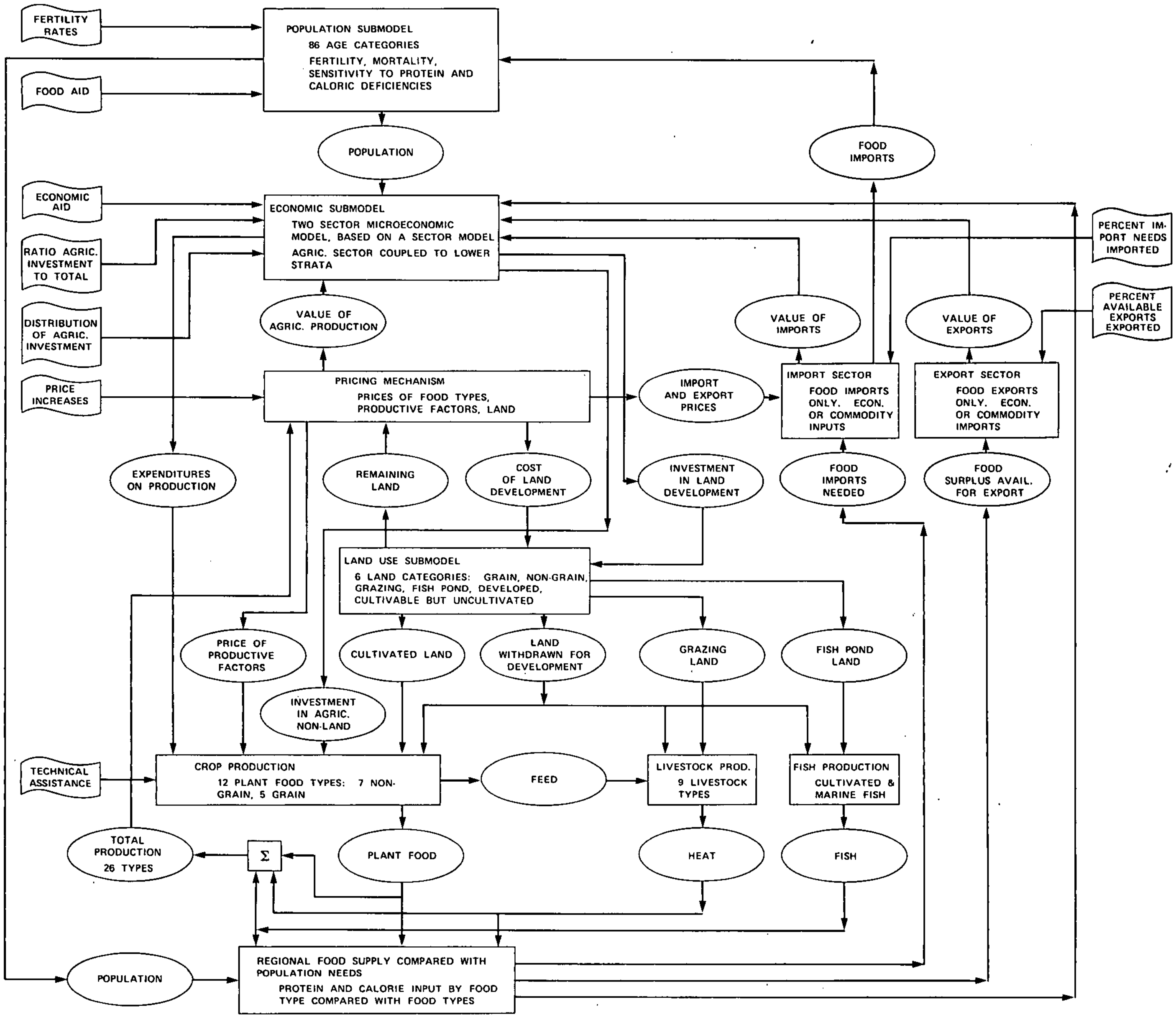


Figure 11.–Integrated food policy analysis model: structure and principal interrelationships between strata and sectors.

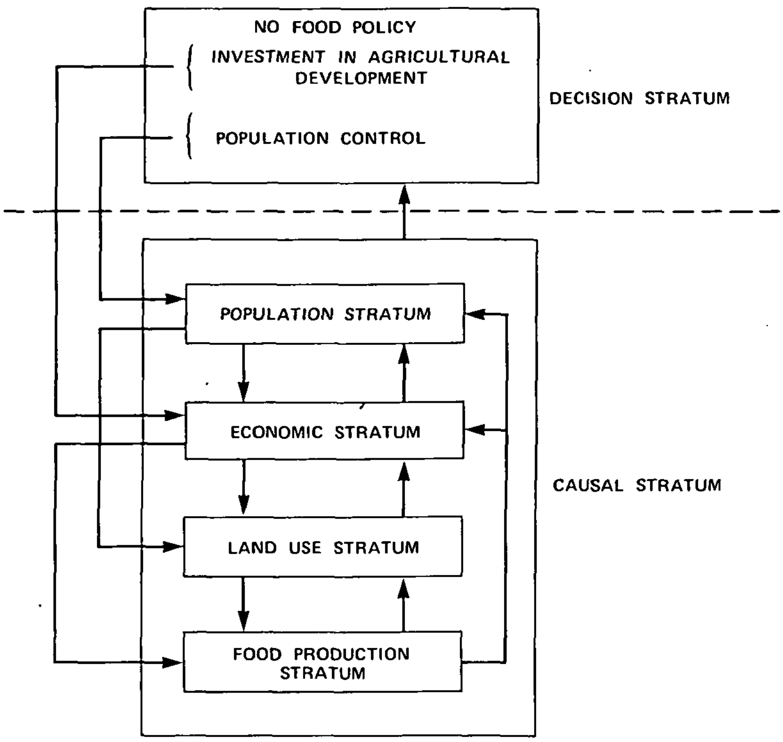


Figure 12.–Integrated food policy analysis model: regional policies.