COMPREHENSIVE RESOURCE ANALYSIS: A SYSTEMS APPROACH

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The almost exponential growth in size, complexity and number of problems facing society have significantly reduced the ability of traditional approaches to offer meaningful solutions to these problems. In this light, systems approaches that are less simplistic are very attractive. This paper examines these approaches by reviewing the main characteristics of existing resource planning and evaluation systems; defining criteria for the development and introduction of more advanced, "comprehensive" systems, based on experiences with resource analysis models and large-scale models in industry and government; and identifying critical problem areas and possible pitfalls in the design, development and introduction of comprehensive systems for resource analysis.

Characteristics of Existing Resource Planning and Evaluation Systems

It is not our intention to present an in-depth review of comprehensive resource systems models.1 Instead, we will present brief comments on selected classes of these models including: environmental planning models, general mathematical models, "naive" systems models, detailed mathematical models and conceptual models.

Environmental Planning Models

The approach to environmental planning proposed by Hills [13], Lewis [17] and McHarg [18], is essentially based on systems for classifying land and associated natural resources according to certain physical characteristics.2 Analytic effort has been directed towards deriving methods for evaluation and subsequent treatment of both the physical and intangible qualities of the

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1Summaries of the majority of these models can be found in the literature. In particular, see Kilbridge, O'Block, and Teplitz [15], Hamilton, et al. [11], Steinitz, Murray, Sinton, and Way [22], and Goldner [10].

2An extensive review and critique of these approaches is given by Belknap, et al [3]. For further reference material see the bibliography at the end of their report.
environment. The term systems analysis is a misnomer when used to describe the analytical processes employed in these efforts since the classification schemes upon which they are based do not constitute coherent systems. Either this approach is too weak as a potentially integrative process, or treats too briefly the problems of economic and social evaluation. Strictly speaking, it involves neither modelling nor systems analysis; the term "systematic resource analysis" offers a more precise description. However, such systematic approaches have made significant advances in the measurements of environmental quality, and have given valuable insight into the ecological basis for resource management. In these respects, they provide valuable inputs for more complete environmental systems models.

General Mathematical Models

There are several advantages in attempting to formulate large-scale problems in general mathematical terms. First, the general model offers a conceptual framework for problem definition in the precise language of mathematics and identifies the logics and the techniques to be used for its solution. Further, it eliminates the constraints involved in the problem and gives an indication of the types of variables to be used.

Despite these advantages, the general mathematical model is not a decision-making tool. It cannot be used for practical purposes unless all relevant variables and their interconnections have been defined in full detail. Further, based on these interrelationships, the future movements of all significant variables must be forecasted with adequate accuracy. The development of such detailed models for large-scale problems is a formidable task. In the relatively simple example of land-use planning this would mean taking a complete census of land-inventory, developing a full-scale forecasting model for land-use requirements by zone, and a model for the definition of design standards and of limitations within and between zones. In turn, prerequisites to the development of these sub-models are reliable models for forecasting population growth, industrial and commercial development, social activities, etc., for the planning area. In other words, a relatively straightforward linear programming framework grows into a large-scale exercise in building complex forecasting, planning and control models.

Although laborious and lengthy, the development of such detailed models is necessary if they are to be used for practical purposes. This stems from the very nature of mathematical methods and simulation techniques, in which the validity and usefulness of the conclusions offered by these methods depend on the accuracy of the mathematical statements given and the completeness of the variables used. If the model is not detailed enough and/or does not yield adequate accuracy, it may provide a useful learning experience, but it cannot be used for solving practical problems.

Naive Models

Another approach frequently used is the computerization of previous planning
practices. The basic assumption is that previously employed procedures will present an accumulation of managerial experience and wisdom and therefore the best possible guidelines for decision-making.

This approach tends to overlook a few basic facts of manually based planning procedures, which have severe limitations in terms of (i) the number of variables and observations handled, (ii) the manipulation of large masses of data, (iii) restrictions on the use of mathematical and statistical techniques, and (iv) the lack of flexibility and speed in analysing alternative strategies. Owing to these constraints, the manual system is oversimplified. Further, since it is built mainly on successive judgments (guesses), rather than on objective and quantitative statements, the manual system is apt to change from year to year, in logic as well as in structure. Thus, the computerization of previous planning practices bears the danger of perpetuating past imperfections, errors, and limitations. Because the "naive" modelling approach neither utilizes the capacity and advantages of a computer, nor the potential of advanced statistical and operations research techniques, nor the possibility of building an objective basis for decision-making, it represents a naive approach to model building when taken by itself.

Detailed Mathematical Models

In comparison to general mathematical models, these models take into simultaneous consideration all relevant variables; define the existence and degree of interrelationships among variables by appropriate statistical techniques; include sub-models, often of a general mathematical type, built into a uniform framework; and are tested in practice and evaluated in terms of consistency, stability, accuracy, applicability, and usefulness.

Considering the workload, expense and complexity involved in building detailed mathematical models, it is understandable that their existence is not commonplace in regional or urban planning. Kilbridge, O'Block and Teplitz [15] list twenty existing models in their article that can be counted to varying degrees into this category. Sixteen of these have been developed with practical applications in mind. Examples include the Chicago Area Transportation Model [14], the Empiric Land Use Model (Boston) [5], the Susquehanna River Basin Model [11], the Penn-Jersey Regional Growth Model [8], Projection of a Metropolis (New York City) [4], and the San Francisco C.R.P. Model [21]. These have many characteristics that we listed as prerequisites for a successful detailed mathematical model, but none of them satisfy all the prerequisites.

Conceptual Models

A major criticism of existing resource systems models is that they are conceptually and theoretically deficient. Certainly, relevant theory is as yet too vague to provide the organizing concepts for comprehensive model building. In particular, it is often the case that mathematical statements of models create theory without relevance to either generality and logical coherence, or any intention of testing in a meaningful way. Thus, the modelling
of resource systems will require a refinement of theoretical concepts, and operationally useful statements. As an example, consider Forrester's [9] conceptual model designed to study the growth and decay processes of an urban area. This model focuses on the causes of urban processes rather than the symptoms. Forrester observes that when systems theory takes shape as a conceptual model, discussion and insight of systems behaviour is precipitated, and additional supporting and contradictory information that helps to refine and explicate theory is brought out.

Criteria for Comprehensive Models

A diagrammatic representation of the relationships between the normative, operational and strategic stages in a system approach is shown in Figure 1. Several important features of this figure merit exposition.

First, an explicit distinction is made between policy and programme: policy being defined normatively in terms of goals which are considered to be ideals towards which the system grativates; programme being defined in terms of positive objectives which can be achieved as a means of approximating policy goals.  

Second, the figure shows the temporal relationships between normative, operational and strategic stages.

Third, it illustrates a continual adaptive feedback process which proceeds from programme evaluation to a more precise problem area delineation and a modification of initial goals, objectives and programmes in the light of new information. This systematic approach seems conceptually reasonable, but a more realistic examination reveals some problems.

In industrial and business applications the decision variables of a model can be clearly identified and expressed in dollar terms. The objective of a decision may be to maximize profit, minimize expenses, find the optimum schedule of a product distribution system, etc. The availability of resources and the effects of environmental and social constraints can be also quantified in most cases. In regional and urban planning and resource management, however, the problem is not nearly so simple. To optimize net social benefits requires an a priori definition of what exactly are net social benefits. Further analysis reveals that in most cases the definition of net social benefits is often based on subjective judgments and can be decisively influenced by temporary social and political priorities.

Attempts have been made to overcome the problem of choosing between alternative goals and strategies in the absence of an operationally grounded value system through the application of various ranking or weighting schemes. The problem of the resolution of a goal conflicts problem has received scant

3For more comments on this, see Ozbekhan [20, p. 208].
FIGURE 1. A Systematic Approach to Social Problems

PROBLEMATIC SITUATION
Establishment of a perimeter of concern

INITIAL PROBLEM SPECIFICATION
Disaggregation of area of concern into initial problem areas.

NORMATIVE STAGE

Delineation of Range of choice

Specification of Initial Goals

Determination of Relationships Between Goals

CONFLICT

YES

Resolve Conflict

Establish Policy on Basis of initial Goals Definition of what "ought" to be done.

OPERATIONAL STAGE

Define initial objective. Program determination. What programs "can" be feasibly implemented to achieve initial program objectives and hence approximate policy goals.

STRATEGIC STAGE

Program choice. Evaluation of operational program alternatives. Division as to what program "ought" to be followed.

PROGRAM IMPLEMENTATION

Adaptive feedback to revise problem specification and modify goals and objectives

? Does program achieve objectives

NO

YES

* ADAPTED FROM AN ESSAY BY HASAN OZBEKhan (1, p.212).
attention in the literature.\(^4\) Hill's "Goals Achievement Matrix" \(^{12}\) and Ackoff's "Goal Achievement Transformation Function" \(^{1, \text{pp. } 32-44}\) are two approaches which have been suggested.\(^5\) In relying on relative weighting procedures for evaluating goal priorities both these approaches beg two important questions: (i) How are the weights determined, and (ii) How does one treat weighted goals in an analytically meaningful way, i.e., what is the resultant when weighted goals are added and substrated? Similar evaluative problems arise when attempting to choose between alternative program strategies in the absence of an operationally grounded value system.\(^6\)

Nevertheless, weighting schemes have two main advantages. First, the ranks and weights are flexible and can be changed at any time and a new solution determined according to new priorities. This can yield complete flexibility in working out alternatives and analyzing their impact on the whole system. Second, the actual cost, timing, workload, capital requirements, etc., can be shown in actual dollars and in detail for each of the alternatives considered. This can assist the public as well as the decision makers in understanding the practical constraints of desirable objectives and serve to channel the decision-making process into realistic areas of decisions.

On the basis of this discussion, it is apparent that one of the most taxing areas of research lies in deriving meaningful ways to incorporate qualitative values into the systems specification, i.e., determining value measurement scales which have general applicability. Perhaps the continuing interest in the measurement and qualifications of societal issues, in an effort to utilize social science knowledge for public policy decision-making through the search for objective measures of social indicators, will provide some future guides to value measurement.\(^7\)

Quantification and Model Building

The perennial question about quantification always raises the fundamental objection that there are significant non-quantifiable elements involved in decision-making and therefore, building an elaborate quantitative model will not yield a complete solution. The contribution of detailed mathematical models is to quantify variable interrelationships where quantification is possible, and

\(^{4}\) For a review of these problems, see McLoughlin \[^{19, \text{Ch. } 6}\].

\(^{5}\) See Altshuler \[^{2}\], Dakin \[^{6}\], Dyckmann \[^{7}\], Young \[^{23}\], Levin \[^{16}\], McLoughlin \[^{19, \text{Ch. } 10}\], and Ozbekhan \[^{20, \text{p. } 206}\], for further discussion of these problems.

\(^{6}\) What in fact has occurred where such a system does not exist is that a rather subtle and insidious process of alienation has transpired where feasibility, which is a strategic "can" concept, has been elevated to a normative "ought" position, conveniently obscuring the normative decision-making function.

\(^{7}\) For a review of recent work on social indicators, see Urban Affairs Quarterly, Volume 6, Number 2, December 1970.
hence, to narrow down the area of decision-making into a safe, manageable, practical and preferably "optimal" range of alternative courses of action. Consequently, its main advantages are that it establishes an objective and sound basis for decision-making giving encyclopedic information on the dynamic interactions of all relevant variables, and states these in the clear language of mathematics. It also offers full flexibility to show the possible impact of future decisions. The role of its assistance ends at this point; the final phase of decision-making is contingent upon human choice criteria.

The use of detailed mathematical models in business and industry have shown that there is a considerable improvement in the quality, efficiency and continuity of decisions, mainly due to the proper allocation of functions; namely, that all quantifiable connections are measured by an objective model, interpretations of non-quantifiables are done by analysts and decisions are made by management. The criteria for a comprehensive model may involve both quantifiable and non-quantifiable elements of decision-making as is shown in Figure 2.

Most of the practical problems of this approach will likely arise in deriving a clear distinction between the procedures and methods for incorporating quantitative and non-quantitative model elements into a comprehensive system. It is also likely that the recognition of the practical applicability of these different elements will in turn determine the usefulness of comprehensive system models. In the following sections, we discuss some of the major problems involved in the building, testing, development and introduction of such models.

Building, Testing and Implementing Large-Scale Quantitative Models

The fundamental task in model building is to define the interrelationships of significant variables and to explain and forecast their movements in terms of their interactions. The nature, exactness and rigour of the method used for this purpose, basically governs the applicability of the model and also sets the boundaries of its practical application. The components of the various types of models can be grouped under the five major headings: assumptions, hypotheses, theory, empirical estimates (based on observation and measurement), and quantitative methods. It is assumed that these are familiar terms and need no definition. It is apparent that these components do set different boundaries for the applicability of the various models. Thus: (i) Assumptions may help to simplify the problem, but cannot offer an objective basis for decisions. (ii) A theory may or may not work in practice. Therefore, it cannot be used as a tool for making decisions, but only as a good starting point for a systematic learning process. (iii) The arithmetic expression of previous experience establishes a realistic base for model building. Owing to the absence of the appropriate statistical techniques and proofs, however, the method may be inaccurate and in most cases cannot be used for decision-making. (iv) The application of quantitative methods in model building combined with the use of historical series of adequate length would satisfy all requirements for practical purposes and could be used directly for decision-making within the framework of a comprehensive system.
FIGURE 2. Criteria for Comprehensive Models

Comprehensive Systems

- Detailed Mathematical Models
- Non-quantifiable Elements
- Human Factors
- Non-quantifiable Decision Elements (Value Judgements)

- Physical Environment
- Socio-Economic Variables
- Decision Variables
A more detailed description of the steps involved in the development of quantitative models is given in the flow-chart in Figure 3. The basic characteristics and some of the elements of existing complex system models are shown in Figure 4.

**Practical Problems in Designing, Developing and Introducing Comprehensive Systems**

Some of the "ideal" characteristics of a comprehensive system for resource planning purposes were suggested in the earlier sections. It was also mentioned that the development introduction and operational use of large-scale systems by no means is an easy task to complete. A few of the main problem areas in these activities can be described briefly as follows.

**Volume and Availability of Historical Data**

For many variables, the collection of historical data is laborious and expensive; for others, such data are simply not available. In the latter case, special surveys have to be organized and precede the model building activities. The workload, expenses and time required for these surveys might be rather extensive. This basic problem would be greatly helped by the introduction of a revised, more detailed, flexible computer-based data collection and reporting system developed in a coordinated effort by Federal, Provincial and Municipal Agencies and Statistics Canada.

**Time and Cost Estimates**

Feasibility studies for large-scale projects should be developed by using PERT/CPM techniques. There are a good number of package programs available for PERT/CPM evaluations (for example, IBM's M.P.S. programs) that can be adapted with moderate modifications for the special purposes of a project. The advantage of deriving these estimates prior to the large scale model building effort is that they give a good understanding to the decision-maker regarding the tasks to be performed, the difficulties involved, the critical path of the project, and the total time and expense required. Further, this procedure offers options for evaluating alternative scales of analysis at various levels of cost vs. benefit comparisons. It also offers a good control tool for project management during the development stage of the study.

**Model Building**

Owing to the complexities involved in building models, the development and introduction of comprehensive systems have to be built by interdisciplinary teams. The need for specialization in the large number of sub-sections of the model calls for special expertise in many areas, e.g., the acquisition of the necessary technical expertise in statistical and operational research methods, systems analysis and computer technology and in the actual applications of these
FIGURE 3. Development of Detailed Quantitative Models

Set Objectives

Review Data Availability

Computer Programmes Required

Time & Cost Estimates

Feasibility Study

? Decision on Feasibility

No Rejection in Original Form

Yes Consider Alternatives

Develop Plan & Schedule for the Project

All Data and Computer Programmes Available

? Yes

Model Building

No Technical Testings Are Adequate

? Yes "Live Tests"

No Acceptable

Yes Introduction
FIGURE 4. Basic Characteristics and Selected Elements of Existing Models

<table>
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<tr>
<th>CHARACTERISTICS</th>
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<tbody>
<tr>
<td>PURPOSE</td>
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<td>Learning Process</td>
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<tr>
<td>Simulation of Alternatives for Decision Making</td>
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<tr>
<td>Optimization of Future Activities</td>
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Note. Most of the existing models can be assembled on a modular basis through a combination of the characteristics and elements shown in the above figure. The assembly shown in the figure is an approximation of the Penn-Jersey Regional Growth Model.

- Purpose is to optimize the aggregate rent paying ability by allocation of households
- Basic connections in the model are based on economic theory and intuition
- Uses time series analysis and linear programming
- Used for estimating regional growth

Etc
techniques. Problems arise from the development and operation of large systems, such as the complexity involved in input/output requirements, data manipulation, computer systems and program design, and systems operation and maintenance. "Live testing" may involve the use of the model on an experimental basis for a relatively long period of time. If this is the case, full introduction may be prolonged.

**Introduction and Operational Use**

It is known from experience that when a model is technically ready for introduction, only fifty per cent of the total project is completed. The second half of the workload is the more crucial part: to make the system work in practice and to let the users use it efficiently. Problems in these areas include education and resistance to change.

In a transition period from conventional planning methods to the use of a computer-based systems model it is unrealistic to expect that the users are ready for its daily application. A systematic education of people involved in the use of the system should precede the introduction of the project.

To overcome the natural resistance of the users to changes, practical demonstrations regarding the advantages of the new approach should be given. The best approach is, perhaps, to involve key users in the design and development of the project and assure their confidence in the success of the model based on a sound understanding of its elements.

**Maintenance and Revalidation**

One of the pitfalls of the operational use of large systems is the slow erosion of data purity and of systems discipline. Deterioration in this respect may seriously impair the model and make it unfit for practical use. Further, as all parameters of stochastic models are redefined with every new piece of information, it is necessary to check the validity of the model after each updating. The statistical tools for revalidation must be built into the model and investigations regarding the causes for deviations, if any, should be carried out systematically.

**Conclusions**

The comprehensive systems approach can be applied to a variety of problems in resource analysis, depending on the purpose defined and on the scope of its application. Its main advantages, however, stem from the recognition of the fact that all subsystems representing various problem areas are interconnected and should be considered simultaneously in the framework of a single system. Therefore, the comprehensive systems approach strives for building and operating an overall system for resource evaluation, planning and analysis, instead of attempting to solve part-problems in isolation and on the basis of "piecemeal social engineering."
The major problems and pitfalls of the comprehensive systems approach recognized in this paper were as follows:

1. The absence of explicit goal-setting and definition of objectives in defining a policy and program framework for the analysis and alleviation of regional and urban problems.

2. The inadequacy of the present methods for the incorporation of non-quantified decision variables and intangibles such as social value judgments into the analysis.

3. The deficiencies of an antiquated data base for the compilation of social and economic statistics that is unable to cope with the present and future requirements of precise and detailed analyses of social and economic phenomena conducted at short term intervals.

4. The limitations of the mathematical-statistical and operations research techniques in defining model interrelationships with adequate precision.

5. The enthusiastic misinterpretation of the results from quantitative models and the use of the conclusions from these models beyond their area of application.

6. Our general inexperience in decision maker-model-machine interactions.

7. The absence of a realistic "feasibility" evaluation of time, cost and workload requirements further design and development of comprehensive systems and the introduction of large scale planning models.

8. The necessity for the establishment of a reliable system of maintenance, and a need for a revalidation of the model after each period of updating.

9. The enormous task of introducing large scale comprehensive models for operational use. Problems here include the education of a large number of users and overcoming the natural human resistance to change.

It would seem that we are presently at a stage of development where many of the characteristics and elements of the models which we have discussed do co-exist. Although the various types of models do serve some useful purpose, these combined advantages may be built into the framework of the comprehensive systems approach. Furthermore, it is apparent that the large scale complex problems involved in urban and regional planning cannot be solved in a permanent and systematic manner unless an analytical tool matching their complexities is being employed. We are presently at the stage of development where some of the conventional simplistic planning methods are becoming obsolete and the daily practice of planning and analysis is beginning to embrace the comprehensive systems approach with its requirements for decision maker-model-machine interaction, advanced quantitative methods, and computer applications.
REFERENCES


