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The Evolution of Socio-Economic Modeling in Canada

R. B. HOFFMAN and B. C. McINNIS

ABSTRACT

For the past 15 years the authors have been associated with a research program concerned with the development of structural economic models that had their origins in the input-Qutput models of Leontief. This program has produced a set of conceptual tools embracing a new approach to socio-economic modeling which we term the "design approach." This approach draws on general systems theory and control theory in application to large social systems. Also emerging from this program as its test prototype is a particular set of models designed for society wide resource analysis and a set of software tools within which design approach models can be designed, implemented, and operated. The design approach provides a new method of assessing technologies in regard to their overall socio-economic resource impact. The objective of this paper is to describe the unique institutional setting and the particular issues which provided the setting and the motivation for embarking on a large scale modeling program. The paper is organized chronologically, describing first of all the evolution of the program approach, the software tools, the Socio-Economic Resource Framework (SERF), which is the prototype set of models that have been implemented, and some results obtained from it.

Origins

The structural model program had its origins in the Statistics Canada program of compiling input.~)Utput tables. With the completion of the first commodity-by-industry input-output table for Canada for the reference year 1961, a unit was established in Statistics Canada to implement models based on the input-output tables and to provide access to them on a client service basis. In 1973, this unit became the Structural Analysis Division, a research staff consisting of, on average, ten researchers with support staff.

The first generation of models developed by the Structural Analysis Division consisted of comparative static input-output models. To the national input-output model [9] was added a price propagation model, an interprovincial input-output model, and an energy component of the national input-output model. These models were used to perform comparative static and partial impact analyses: for example, the impact on employment and income of a major project or an export sale, the impact of oil price change on the consumer price index, the calculation of the energy embodied in a bill of final demand.

Two issues emerged during the decade of the 1970s which stimulated the development of time-structured input-output models: The energy supply shock originating from the OPEC Nations, and the industrial strategy debate in which the further fabrication of raw materials and the concurrent development of the manufacturing base were seen as the means of maintaining full employment in Canada.

R. B. HOFFMAN and B. C. McINNIS are currently senior project managers at the Waterloo Simulation Research Facility, Faculty of Environmental Studies, University of Waterloo.

Address reprint requests to Mr. Clive Simmonds, 66 Lyttleton Gardens, Ottawa, Ontario KIL 5A6, Canada.

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The Long Term Simulation Model (LTSM) developed in the period 1974-1976 was the response *to* these issues [5, 10]. The LTSM linked a population model to a final demand model which transformed the components of gross national expenditure by category of expenditure into demand for commodities in a top-down fashion. Final demand by commodity was passed to an input-output model which calculated industry activity levels. Import share coefficients were modifiable in order to assure an international trade balance on current account. Labor supply was calculated in the population model and labor requirements in the input-output model. Subsequently, a detailed residential energy model and a domestic appliance model were implemented both as stand-alone models and as submodels within the LTSM [5, 6].

From the experience of using the LTSM to support a series of studies, a number of provocative or counterintuitive results were indicated, which stimulated further model development work in order to substantiate them. For example:

- Employment was found to be insensitive to both the level and composition of foreign trade. This result countered the industrial strategy hypothesis that the model was intended to substantiate.
- The supply of labour tended to exceed requirements for labor in increasing amounts until at least the turn of the century. Four factors could be identified which led to this result: the passage of the baby boom cohort through prime labor force ages, increased female participation in the labor force, saturation in the demand for consumer durables, and the accumulation of increases in labor productivity.
- The growth and age structure of the population, taking its dynamics from the high birth rates of 1950-1965 followed by a steep decline to below replacement, in conjunction with stock/flow modeling of housing, indicated that the number of new houses required to maintain the stock at an appropriate level would halve by the year 2000.
- Future rates of growth of domestic energy demand were found to be significantly lower than those observed in the decades ofthe fifties, sixties, and early seventies. Furthermore, energy requirements were found not to be proportional to GNP.

The energy analysis work led to several conclusions with respect to the analysis of natural resources. Resource questions are clearly dynamic, involving the interaction of population, economic growth, and lifestyle change with the structure of production in general, and the resource-supplying sectors in particular. Over the longer term, it is the problem of transition from one resource base to another, or from one technological regime to another, and the time available for such transitions, which are paramount. Renewable resource questions are also dynamic, but hinge more on the issue of sustainable yield than the cycle of exploration, development, exploitation, and transition.

The experience of linking the stock/flow models of housing and appliances to demographic variables led to the conclusion that the interactions among stocks with different life profiles provides interesting insights into system dynamics.

National accounting and in particular input-output accounting make use of accounting identities in each time period. These identities equate the supply and disposition of each commodity and the inputs and outputs of each sector, and as such, they provide coherence to economic information. However, economic information has not been subject to stock/ flow accounting over time. Once the accounting is in place to keep track of the vintages of stocks over time, it may then be interesting associate operating or use characteristics with vintages. It became clear that the representation of composition by means of the

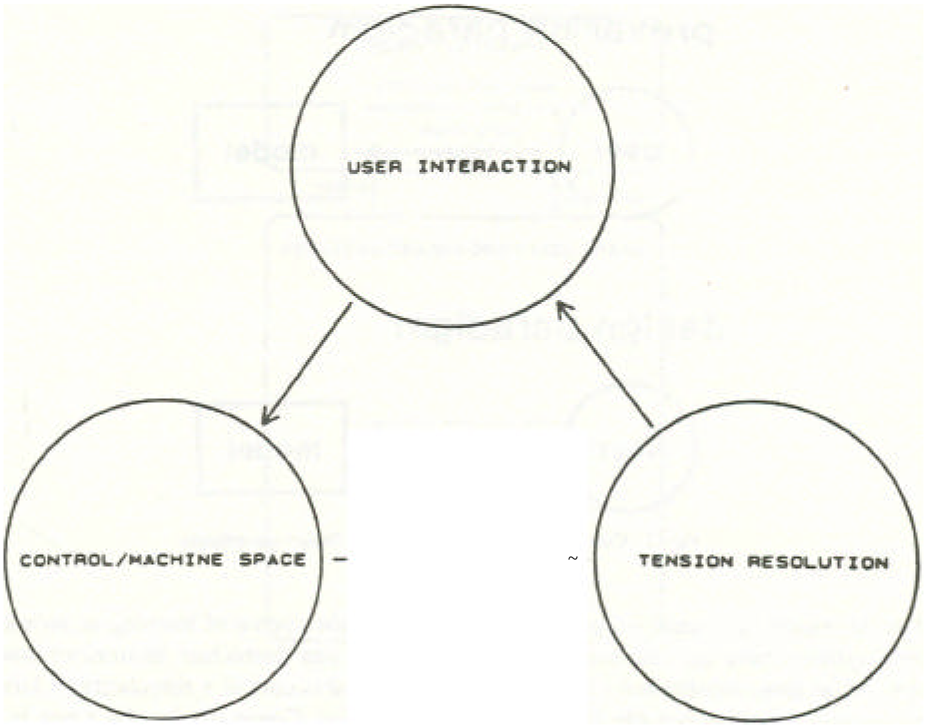

Fig. 1. The design approach.

disaggregation of variables whose linkage was at the macro-level could not adequately handle the stock/flow accounting. Consequently linkages must be made at the microlevel. This has lead to a preference for a bottom-up approach to modeling.

Finally, a great deal was learned with respect to the management of the design, documentation, implementation, and use of large-scale models. Modeling software has traditionally been oriented to the solution algorithm for solving problems, but for these new issues data management have become a more serious, if not the paramount, problem.

Work on the development of a new modeling framework, SERF, designed to incorporate the lessons learned from the LTSM experience commenced in 1982. The first version of SERF became available in 1983 as documented in the *Users Guide to the Socia-Economic Resource Framework* [10]. A second version of SERF became operational in 1987. It is documented in the SERF, Reference Manual [12] Version II.

The Design Approach

From the experience of the Structural Analysis Division in designing and implementing successive generations of input~utput type models has emerged an approach to modeling, namely, the design approach.

There are three facets that distinguish the design approach: the interactive role of the user, the separation of physical transformation processes from decision processes, and the concept of tension (Figure I).

In the design approach the user of the model is an integral part of the system (Figure 2). Here the concept of user extends to include the society he/she represents. The user explores possible future trajectories through simulation. Exploration is a learning process.

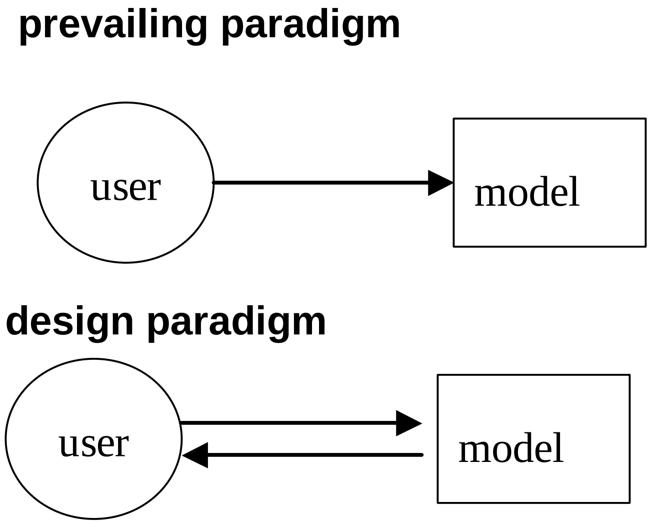

Fig. 2. Comparison of prevailing and design paradigms.

Thus the modeling system is open to the user who is the source of learning or novelty. Open systems have the interesting property that they can restructure themselves when they are far from equilibrium [7]. The restructuring that occurs at a singularity or bifurcation point is not predictable from past system behavior. Consequently, the future is in principle unknowable. This role of the user is in contrast to the macro-econometric paradigm that can be characterized above as applying Newtonian scientific principles that the observer (user) is outside the system and that once the laws of motion of the system are known, the entire trajectory of the system can be known as well. The concept of process is fundamental in the design approach. It is a dynamic concept concerned with the transformation of a stream of input flows into a stream of output flows. According to Capra [1], the concept of process is primary: The structure we observe is the manifestation of underlying processes. In order to understand structure, one must understand the processes that give rise to it.

The design approach distinguishes two kinds of processes: those that transform materials and energy; and those that transform information (Figure 3). The former constitute "machine space"; the latter "control space." Processes in machine space are subject to human influence or control. Some processes occur within human created environments or artifacts. In this case humans control the design and construction of the artifact as well as the operation of the process within it. Other processes occur in the natural environment; these are subject to human influence.

Human designed processes are overdetermined in terms of their control variables. This gives rise to the possibility that the individual processes or machines get out of sync. Tension is a measure of the extent to which the set of a machine are out of sync. Machines are coordinated through control space (Figure 4).

In the design approach the user of a model assures consistency among the machines that are represented in the modeling framework. This he does in one of two ways: Machines are run, and the values of tension variables are calculated. The user resolves tension to his satisfaction by resetting control variables (Figure Sa). This process can be automated by allowing the user to specify feedbacks from output variables back onto selected input or control variables (Figure Sb).

If there are models of decision processes in control space, the control variables are

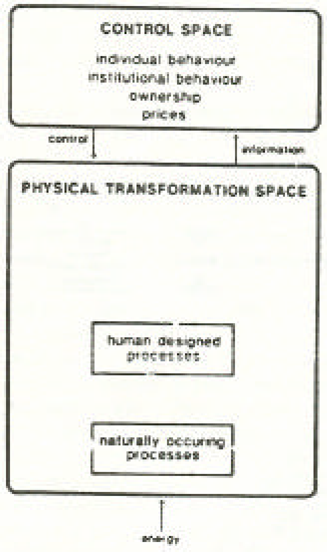

Fig. 3. Control space and machine space.

set according to those models. To the extent that tensions arise when the models that represent machines are executed, the user intervenes by changing the decision rules of the decision processes or by restructuring the control space models (Figure 5c). It is generally the case that there are many ways to resolve a particular tension, so that the model user has the opportunity to explore the various means of tension resolution. Note as well that what constitutes tension may well be subjective.

The design approach is thus an approach to modeling that makes the user or the society that he/she represents an integral part of the modeling system through tension resolution.

Software Tools

Both the scale of SERF and the features of the design approach present considerable challenges for software engineering. From the experience of developing SERF and its predecessors has emerged a number of strategies that have proven to be effective in the resolution of these problems. These strategies are now embodied in a set of software tools which are intended to support the design, documentation, and operation of large-

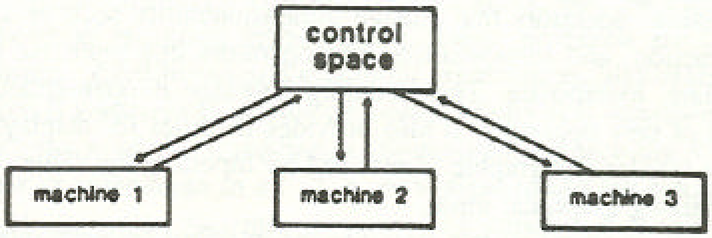

Fig. 4. Interaction between control and machine space.

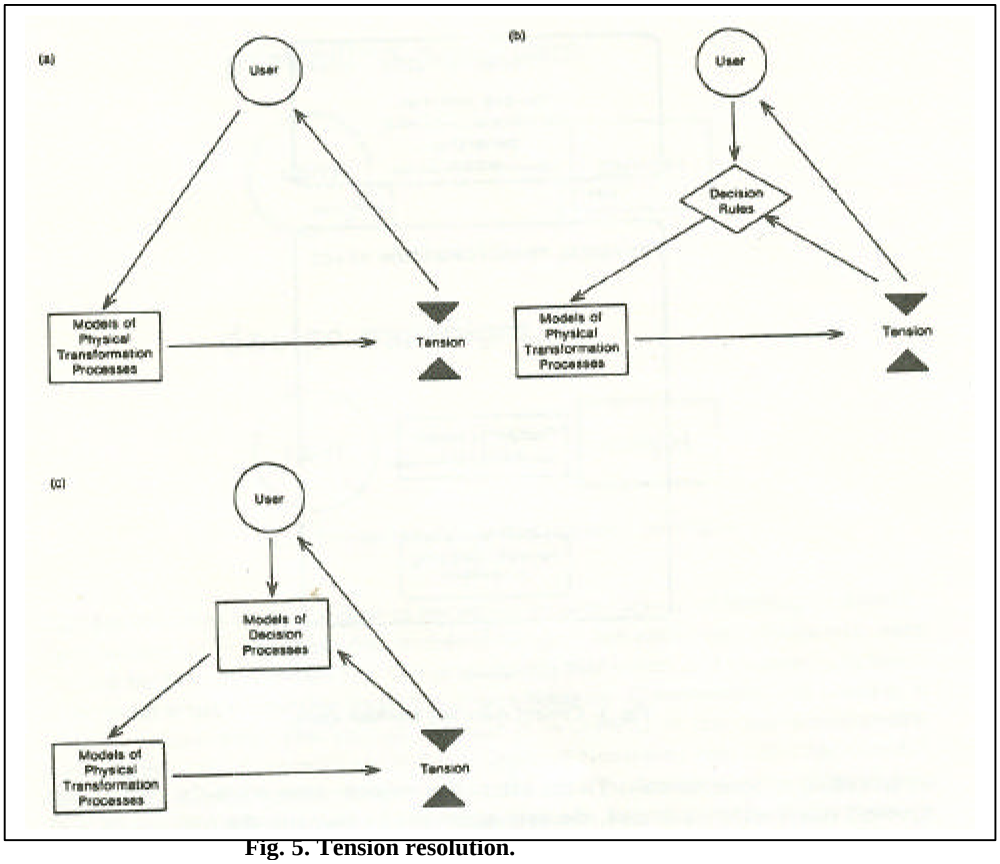

Fig. 5. Tension resolution.

scale models. These software tools consist of an interpreted, interactive, modeling language for managing and manipulating the variables and the relationships among them that constitute a model, and a system for scenario and model management.

The modeling language stores and manipulates multidimensional arrays. For example, "population" may be represented as a single variable where "population" is broken down by sex, age, location, and time. Thus the single variable "population" may contain a set of 2 (sexes) x 100 (age groups) x 10 provinces x 100 (years, 1900-2000) or 2 x 105 values. The description of the variable, "population," includes its name, the ranges of its dimensions and associated title sets, units in which it is measured, and the formula or equation that defines it. Clearly the variable "population" may have more than one set of values associated with it.

Data manipulation is accomplished by operating on multidimensional variables. The operators include the standard arithmetic operations of addition, subtraction, multiplication, and division, operators that change dimensionability such as aggregation, concatenation, extraction, and transposition, and operators that represent special functions such as interpolate, extrapolate. The modeling language is open-ended with respect to the introduction of new operators. It also provides facilities for displaying the values of variables in both tabular and graphic format and for inputting the values of variables from files and by digitizing graphical input.

The model management system provides the interface between models expressed in terms of language statements and the user of those models. It represents the structure of the models under its control and manages scenarios. Scenarios are the sets of the values of input variables that produce values of output variables that constitute an application of a model.

The model manager makes use of multipage diagrams with successive levels of detail to represent the structure of models. The diagramatic language separates symbols that represent variables or the objects to be manipulated by a model from the procedures or equations that represent the relationships among variables.

Variables are connected to procedures by relational flows, which indicate that a variable is input to a procedure or output of a procedure. These relational flows are visually distinct from procedural flows which connect procedures and show order of execution or flow of control. With each graphable object is associated text which constitute the labels on the object, and more detailed information describing the structure of the object and the meaning of the contents of the object.

The model manager facilitates the creation of diagrams through the use of function keys representing different objects. The set of predefined objects is expandable. Connections between objects are easily drawn. These connections are remembered so that diagrams can be redrawn as they are being edited. Menus are associated with object types that prompt for labeling information and for the text associated with each object.

At the lowest level in each diagram symbols representing variables correspond to the data structures and values manipulated by the modeling language and the symbols representing procedures corresponds to files of statements. Higher levels in the hierarchical structure of the diagram contain meta data that describe the meaning of scenarios and the structure of the model.

Creation of a scenario is accomplished by navigating through the hierarchy of multipage diagrams that represent the structure of the model. At each node in the hierarchy, the user can browse the meta data describing existing scenarios. At lowest level nodes the user can view the values of input variables that constitute a scenario or he can create new sets of values. Thus new scenarios can be created by mixing existing sets of input values and by creating new sets of values. The node manager keeps track of the set of input variable values that constitute a user's scenario and stores only unique values. Once a complete scenario has been defined values of output variables can be calculated. Only the code necessary to produce the output variables required need be executed. As well, only the subtrees whose input has been modified need be executed.

At each node in the hierarchy, the model user may enter text which describes the meaning of the scenario he is creating. This text along with graphs and tables of the values of variables form the basis for a document reporting the results of each analysis. Results comparing two or more scenarios can be obtained as well.

The Socio-Economic Resource Framework

SERF is intended for the analysis of issues involving the availability and disposition of human and natural resources, the transition from one resource base to another, the impact of technological change on employment and skills, and the impact of changing population composition on social infrastructure. These problems are characterized by compositional change, substitution and efficiency possibilities, and externalities.

SERF Version II consists exclusively of models of physical transformation processes in the "machine" space of the Canadian socio-economy. There are 43 independently executable models or calculators in all. It is convenient to use the concept of hierarchy for the purpose of exposition and management. The conceptual hierarchy is shown in

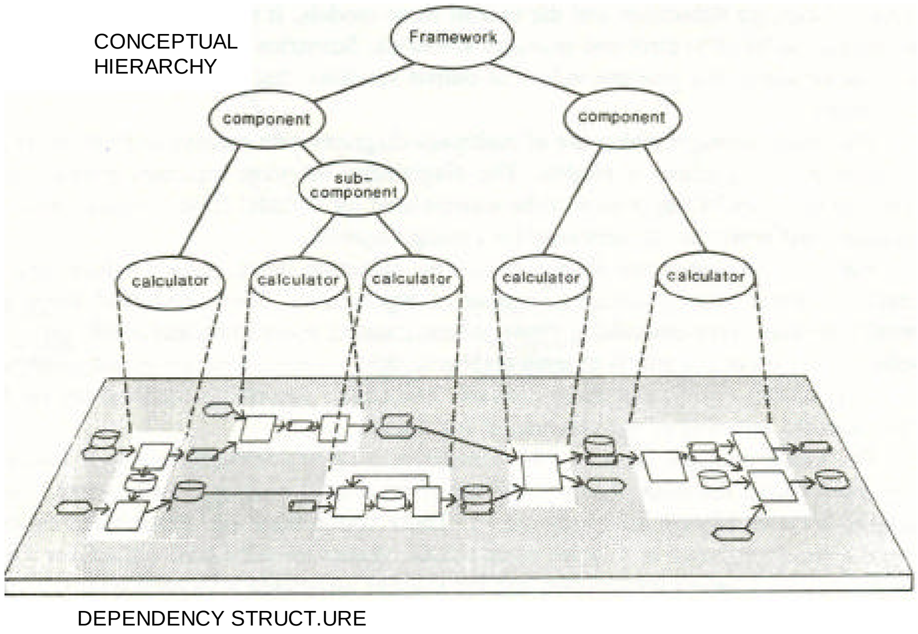

Fig. 6. Hierarchy and dependency.

Figure 6. In SERF Version II the calculators are grouped into 20 subcomponents which in turn are grouped into four components. The complete hierarchy is shown in Figure 7.

The four components and the major flows of information among them are shown in Figure 8. The demography component represents the basic demographic processes of population dynamics, household formation, and labor force participation. It keeps track of population by age and sex, families characterized by size and age, and the availability of labor by age and sex. Spatial distribution is represented as well. The control variables reflect decisions with respect to fertility, migration, family formation, and labor force participation.

The consumption component represents the infrastructure or stocks of goods that yield services required by human society. In general, it calculates the flows of goods, energy, and labor that is required to put infrastructure in place and to operate it. The consumption component keeps track of dwellings, consumer goods, hospitals, schools, motor vehicles, highways, airports, railroads, port facilities, hotels, restaurants, department stores, banks, recreational and cultural facilities. It is clear that the consumption component does not correspond to "consumption" according to national accounting definitions. The emphasis here is on the availability of stock, not on the measurement of the value of the flow. The control variables reflect decisions to put infrastructure in place. By having the consumption component follow the demography component, these decisions can take the form of parameters that reflect accessibility or intensity of use per capita or per family. In this way consistency between population and infrastructure can be assured. It is clear that the models in the consumption component are dominated by stock/flow accounting and, as such, are analogous to population accounting. For goods with short lives the stock/flow models become their flow equivalents.

The fabrication and assembly component represents the processes that transform materials and primary energy into finished goods that are required by both the consumption and material resources components. It keeps track of the stock of productive capacity

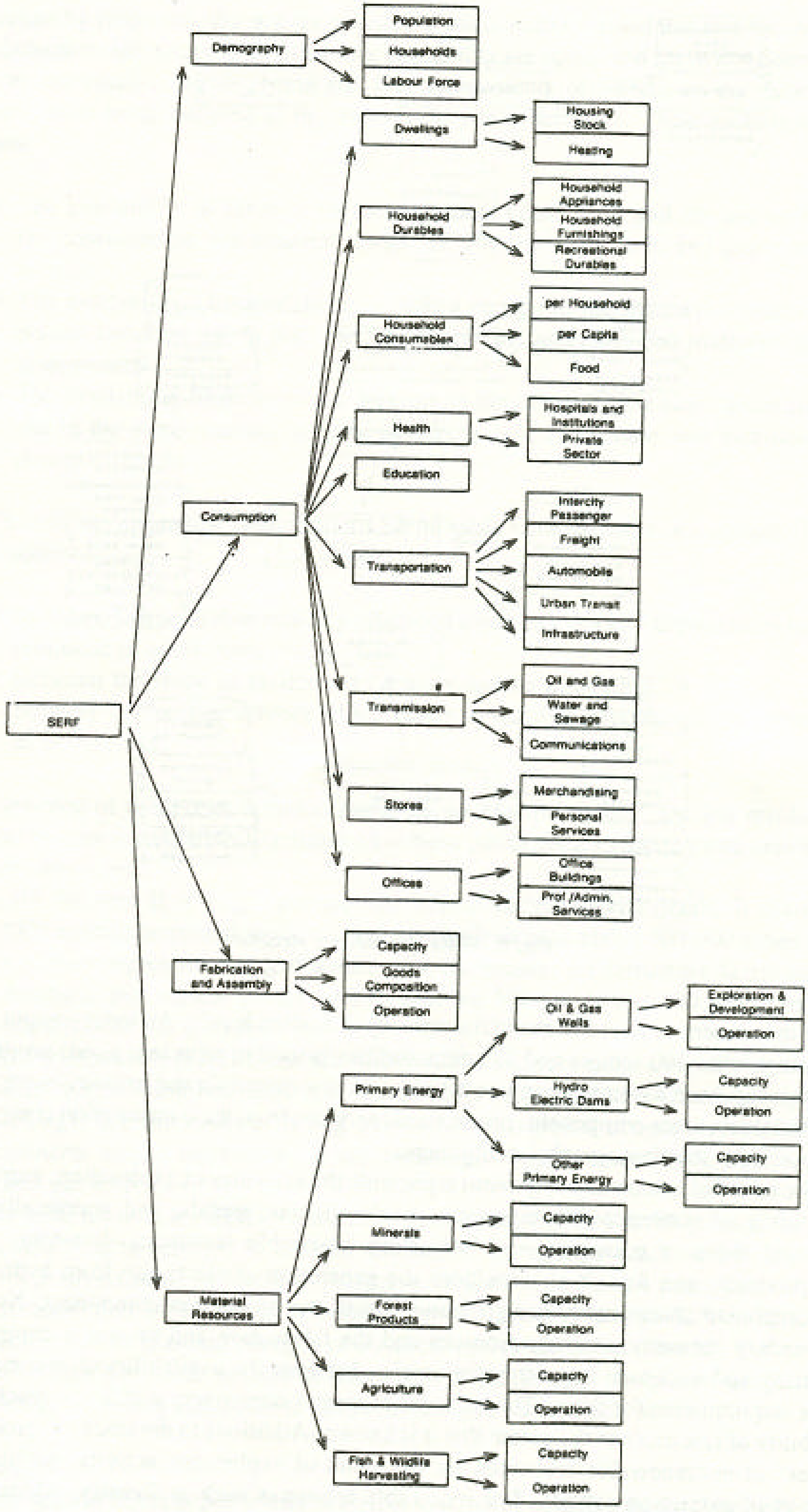

Fig. 7. SERF conceptual hierarchy.

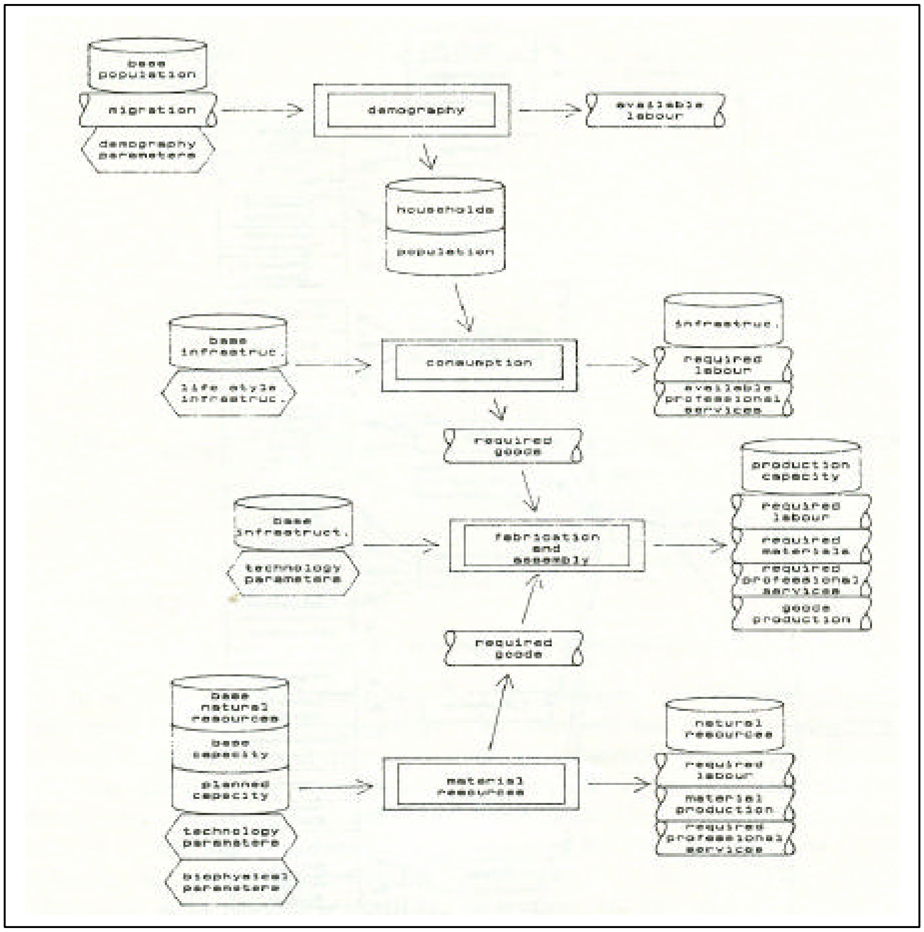

Fig. 8. SERF dependency structure.

and the investment required to maintain capacity at desired levels. An input-output model that distinguishes 200 sectors and 500 commodities is used to represent goods production. The fabrication and assembly component requires raw materials and primary energy from the material resources component, professional services from the consumption component, and labor from the demographic component.

The material resources component represents the activities of exploration, extraction, and refining of nonrenewable resources--<:oal, oil, gas, metals, and nonmetallic minerals-and those of managing and harvesting renewable resources-livestock, crops, forest products, and fish. It also includes the generation of electricity from hydro sites. This component shares many design features with the production component. Note that the boundary between material resources and the fabrication and assembly components is arbitrary and is chosen to portray the tension between the availability of raw materials and the requirements for them. The material resources component also keeps track of the availability of resources to the extent that it is known. Additions to the stock of "producible reserves" of nonrenewable resources are the result of exploration activity; withdrawals, the result of extraction activity. For renewable resources such as forestry, additions are the result of growth which may be enhanced by forest management activities, but may be retarded by pollutants that are the result of human activity. Land use and the evolution ofland characteristics such as soil quantity and quality are accounted for in this component.

The information flows among the four components of SERF, or the dependency structure, have been designed to highlight three sets of tensions. These include tensions between:

. The availability of labor in the demographic component and the use of labor in the consumption, the material resources, and the fabrication and assembly components.

. The availability of materials and primary energy in the material resources component and their use in both the fabrication and assembly and material resources components.

. The availability of professional services in the consumption component and their use in the consumption, material resources, and fabrication and assembly components.

These are by no means the only tensions identifiable with SERF. For example, there is also tension:

. In the exchange of domestically produced materials, goods, and services for those produced in other countries. . Between the stock of productive capacity and its utilization. . Between expl,?ration activity which yields producible reserves and extraction from these reserves.

In the absence of models of decision processes in "control space," tension resolution is achieved by user intervention. Facilities have been put in place to incorporate user defined feedback structures.

SERF Version II is large in scale and rich in compositional detail. It consists of about 2000 multidimensional variables that are equivalent to about 400,000 times series. These variables represent vintaged stocks such as houses, infrastructure facilities, consumer durables, and vehicle stocks, and as well the 500 goods and 200 activities of the input-output tables for Canada.

Most components in SERF are national in scope and recognize no spatial distribution of activities within these boundaries. A number of subcomponents, including population and dwellings, are implemented using provincial or regional geography. In principle, subcomponents can be represented at any meaningful spatial scale, for example, basins for oil and gas activities.

The time horizon for SERF is relatively long term, from 30 to 50 years. It is a time horizon that long is required to analyze decisions that must be made in the near future that involve investments in facilities that have useful lives of 20 or more years.

The time step of one year is common to all components in SERF. Short term phenomena such as seasonal changes or business cycles are not addressed. The structure of SERF makes it possible to have different time steps for each component provided that communication among components occurs at one-year time intervals.

Application

This section of the paper briefly describes a series of simulations that were performed in order to analyze the availability and disposition labor in Canada over the longer term

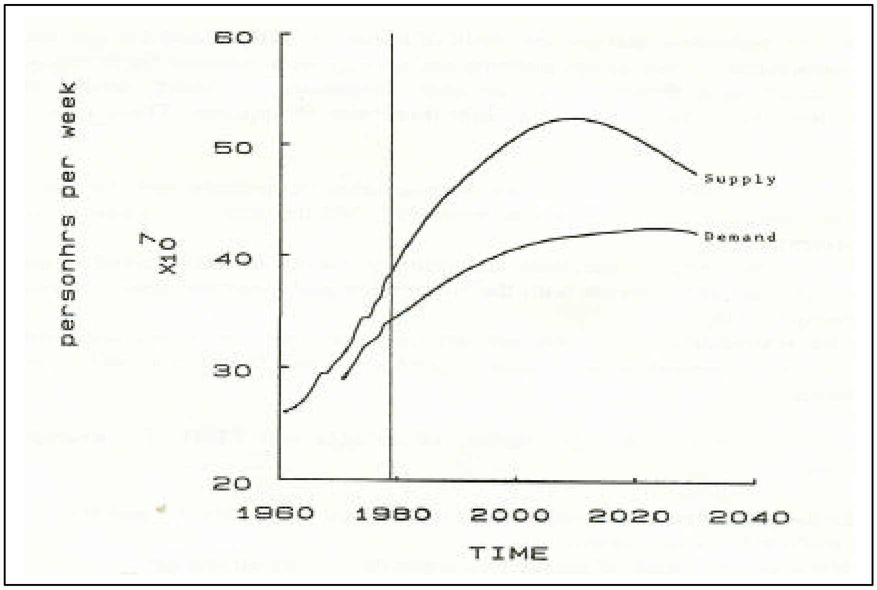

Fig. 9. Labor service supply and demand r,eference simulation.

particularly with respect to the impact on youth unemployment [8]. The simulations were designed to identify the major factors that determine labor availability and disposition and to test the sensibility of results to changes in them. Note that SERF distinguishes two concepts with respect to the measurement of labor. The first is a flow concept measured in units of labor per unit of time, usually person hours per week; the second is a stock concept measured in numbers of people at a point in time. The stock concept is used in the familiar measures of unemployment. The relationship between the stock and flow concepts is not fixed.

The simulations focused on the tension between the availability of labor and the requirements for it. This tension is expressed in terms of the flow concept; accordingly it should not be equated with unemployment. Figure 9 characterizes the results of the simulation in terms of the tension. The results of the analysis are described as follows.

The most general results of this analysis would seem to be that the combination of demographic changes, saturation effects, and increases in productivity are likely, under most of the conditions projected here, to substantially increase unemployment until some time after the turn of the century. The two most promising strategies for reducing unemployment (other than decreased productivity) would seem to be a shorter average work week or substantial increases in consumption of nondurable goods. However, the former could simply represent another version of increased unemployment (i .e. , a smaller funtime work force creating a shorter *average* work week) unless significant job-sharing were to occur. Either version of a shorter work week raises significant distributional issues.

It is important to reemphasize here the nonpredictive nature of ,this analysis. Most of the scenarios and variants shown here indicate a labor service tension that is approaching 20% by the end of this century. Clearly one could expect significant social and institutional changes to occur before such values would be reached. This analysis, therefore, by no means predicts the future. Instead it suggests the existence of certain trends and relationships that must be taken account of in our attempts to create a desirable future.

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