AN APPROACH TO MODELING URBAN GROWTH AND SPATIAL STRUCTURE

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The approach to urban modeling presented here seeks to extend the focus of model building activity from a product to a process orientation. By embedding model building in a dynamic feedback process, it is hoped that the resulting models will change and adapt to the needs of users over time. Thus a continuum develops beginning with model design and ending with public involvement and implementation, which in turn feed back to model design to form a loop. Model building is the subject of the process, and the model presented here includes three principal submodels: population and demographic change, regional economic forecasting, and land use. Taken together, these three components form a module that in turn can be interfaced with a variety of other regional simulation models. This module is currently being designed to interface with models of regional transportation, air and water pollution, health care, site servicing costs, and local government finances. Both the module and the process have evolved with flexibility and maximum use as prime design criteria. An early version of the module is already programmed and operational. With widespread use, further additions and modifications will be made both in the components and in their interaction. The main thrust of the paper, however, is on use and dissemination of the process. The module, although worthwhile in its own right, is merely a phase in the process. The most critical element is public involvement in, and knowledge of, the models. An informed and cautious public is the key to the process and spells the difference between the present model building approach and those that have preceded it.

•THE transportation planning process has evolved quickly during the past two decades. However, there is increasing concern that the evolutionary forces are losing out to inertia and institutionalization of procedures. Writers have recently pointed out new directions in which they feel transportation planning might move (10, 28, 30).

The thread that seems to run through much of the concern about urban transportation planning is the relevance of the process to new and emerging problems that the planner is facing. The problems include public participation, a variety of environmental and nontransportation and noneconomic factors that relate to transportation, the impacts of transportation and land use on each other, the lack of in-house expertise, and the increasing sophistication and esoteric nature of transportation and other urban modeling techniques. Thus, Voorhees and Bellomo (38, p. 147) have stated the following:

> The selection of city structure and broader considerations relating to the environment and living preferences are the key decisions that must be made. Once city structure and environmental objectives are selected, care must be exercised by the planner to develop a transportation system that is directed towards that particular city structure and to assure that the broader environmental considerations are met.

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Kochanowski and Wickstrom (18, p. 12) raise questions about the spatial specificity and time horizon of current planning procedures. They have observed the following:

> The urban transportation planning process must be made more relevant to decision-making and implementation. Most transportation decisions are not made at the regional scale, but at the corridor and project levels. Much of today's transportation planning methodology can be applied at these finer degrees of planning, but new methods and techniques specifically tailored to these scales need to be developed as well. At the same time, much broader regional studies involving human values, as well as physical and economic considerations, should be undertaken. We badly need more specific, fine-grained tools for short-range planning, and also broader social and economic planning tools to apply at the regional level.

Finally, in another broad brush summary of needed new directions, Roberts (30, p. 44) has concluded:

> The challenge to urban transportation planning is a challenge to how effectively we can utilize the model building capability we are slowly acquiring, the computing power we have developed, and the understanding of the nature and purpose of planning we have discovered to explore the possibilities that the technology of the future holds for the city.

Each of these authors has stressed the kinds of problems summarized at the beginning of the section. These writers and others (10) in the transportation field have in particular begun to stress the need for larger scale human input either through inclusion of more and better behavioral aspects or through direct citizen participation in the transportation planning process.

The following describes an approach (a process) to modeling urban development that we feel is generally applicable to urban policy formulation, testing, and implementation. Although not oriented to transportation specifically, transportation planning is both a needed input to the process and a likely user of it.

APPROACH TO MODELING URBAN DEVELOPMENT

The principal focus of our work is the creation of a model building process, of which a set of models is a part. The models, however, are not seen as an end in themselves but rather a focus for, and means of, evolving the process. This work is being undertaken at the University of British Columbia in close conjunction with various levels of government and, most importantly, with a variety of citizen groups.

The two essential elements in the process relate to synthesis and usability. Figure 1 shows the kinds of syntheses we are attempting, and Figure 2 shows model development and use. The syntheses we are seeking begin in the university and extend out to other institutions and then to the body politic. Thus, first we have sought to integrate a variety of disciplines and methodologies that abound on a university campus and to focus this diversity of expertise on problems of modeling our urban environment. The work is therefore interdisciplinary. Next, it is necessary to move outside the confines of academe to various levels and departments of government. Thus, the synthesis is an interinstitutional one as well. Finally, it is necessary to proceed further still and integrate this interinstitutional synthesis with the general public. This last synthetic activity is more than public involvement in the usual sense; it is intended to reach citizen groups, private businesses, and, most generally, interested citizens as individuals.

The first two levels of synthesis have been achieved. A dozen disciplines are involved from the university, and we are currently working with all four levels of Canadian government. The hardest part, however, is yet to come; it involves reaching out to the general public. This task has just begun and is expected to last well past the planned 5-year duration of the project. (We are currently beginning our third year.)

These syntheses are not unrelated to questions of model development and use (Fig. 2). For us to construct a policy-testing model of any use and interest, a wide variety of individuals and institutions must be involved. Thus, interinstitutional and public involvement are seen as means of achieving the process, which in turn has as its goal use. Without open access and actual use, the models will undoubtedly take their place alongside numerous others that have been developed during the past decade only to be quietly shelved after a brief period of trial. The whole purpose of evolving a dynamic and ongoing process (as distinct from the product, the models) is to bring use directly into the model development framework. With continued use and reevaluation, there will exist continued need for refinement and redevelopment. The process will entail an ongoing evolution of the models such that use and development will blend as different elements in a modeling continuum—the model building process.

One other point should be made about the role of the public. This relates to questions of values, preferences, biases, and so forth. The module to be described is not value-free in the traditional sense. The policies that were initially designed to be tested by the module (though not the outcomes, which are hopefully functions of system dynamics and not our values) are certainly reflections of our biases, as are the very components that we have included in the basic module. However, we like to call the models "value-variable," acknowledging that values are important but that they are user-determined and subject to direct change through intervention. The module is programmed as a real-time interactive system to facilitate such user selection of value assumptions.

This highlights one of the most important functions of public use, i. e., public evaluation of simulation output. The models are intended to provide an "if-then" format for questioning. The user specifies an "if" question or assumption, and the models return the likely consequences of such a question. The consequences can be specified along a variety of dimensions from land use, to employment, to migration, and later to congestion, air and water pollution, and so on. These outputs really represent a series of social indicators. However, unlike other investigations that promote social indicators, we will not, by conscious decision, specify any system of weights that will allow these index elements to be added to yield indexes of quality of life, pleasantness, well-being, etc. Such indexes of livability can only be formulated by individuals. Individuals do need information to derive such a measure (the derivation itself being an extraordinarily complex synthesis). The simulation system is designed to provide such indicators. It explicitly fails to supply weights to combine these indicators into a single index, leaving this synthesis to the individual. Simulation provides an important vehicle, therefore, for putting individual values back into public decision-making and thus avoiding the need to create arbitrary or narrow weighting schemes to evaluate alternate outcomes. Computer technology provides us with the opportunity to communicate with people on a scale and level that have previously not been possible. Whether or not we take the opportunity is another question.

The foregoing has set out the method. The following outlines its application and dwells on the basic simulation module or urban growth and spatial structure, which is the heart of the model building activity.

THE MODULE

The module consists of three separate simulation models that have been linked together. The component models are population, economic, and land use. The population model is a cohort-parity model of natural increase combined with a life-cycle model of migration. The availability of housing also plays a role in the migration component of the population model. The economic model is a synthesis of input-output techniques and simulation. A simulation model is used to generate a matrix of final demands, which are then distributed among the various sectors by the input-output model. The input-output model is in turn linked back to the simulation model with the population model.

The population and economic models are the driving forces behind urban growth. This growth is given spatial form through the land use models, which allocate population and employment to residences and work sites around the urban region. Thus, the land use models translate growth forces into changes in the spatial structure of the urban area. Spatial structure provides a natural focus for interfacing these components. Economic and population growth affect spatial form in the first instance, and spatial elements, such as density and agglomeration, in turn feed back on these two elements of regional growth.

POPULATION MODEL

This model is used to simulate the size and composition of the region's population (27, 14). The model operates on a simulated annual data base that utilizes a life-cycle classification system to describe the population (7, 21). The characteristics of the population considered, therefore, involve age, sex, marital status, age of spouse, and number and age of children. The various components of the model function sequentially to alter the composition of population over one iteration. The model (Fig. 3) is comprised of two major functional components: the natural increase (or more exactly the demographic change) submodel and the interregional migration submodel (16).

The natural increase submodel is further broken down into a number of subcomponents, here referred to as subroutines. The birth subroutine is an extension of the traditional cohort birth models. It is used to determine the effect of age on the probability that a female will give birth to a child and the effect of the number of children that a female of a given age has already borne (parity) (1). This subroutine uses an age and parity specific probability of a female giving birth to simulate the number of births and the age-size composition of families in the region. From the model, therefore, the family size, composition, and life cycle can be estimated, providing important inputs into housing, economic, and transportation models (2, 22, 23, 32). Policy interventions involve simulation of changing age, parity, and age and parity patterns of fertility.

The mortality subroutine accounts for deaths by altering the composition of the data base using the age-sex-marital status-specific probability of surviving to the next age group. Included in this subroutine is an accounting procedure that alters the characteristics of the surviving population on the basis of the change in marital status to widowed inherent in the demise of a spouse. Two other subroutines also result in changes in the marital status composition of the population. The marriage subroutine uses two age and present marital status probabilities of marriage, one for each sex, as inputs to a marriage market process. The separation and divorce subroutine simulates the effect on the composition of the population resultant from marital dissolution. Although divorce changes the marital status, separations were included to simulate the effect on the housing market of the functional, as compared to the legal, demise of the marriage. One further subroutine simulates the process by which non-nuclear-family households form for reasons not related to the housing market, such as cultural preference: This process is referred to as basic clustering. The formation of a household as a result of the cost and/or availability of housing, forced clustering, is included in the housing model (25).

The migration submodel simulates the size and composition of migration flows into and out of the region. Because the region is characterized by very dominant in-migration for reasons that are apparently more directly related to complex life cycle, life-style, and cultural factors than to economic factors, modeling interregional migration has proved to be very complex (6, 34). The migration model, as currently conceived, compares the characteristics of this region to those of other regions. Interregional migration is simulated using the results of this comparison and stage-in-life-cycle specific propensities to migrate (17, 41). The factors considered in the regional comparisons are included under the headings environmental (climate, recreation, and pollution), economic (wages, jobs, cost of living, and availability of housing) and cultural (diversity of activities). The migrants are characterized, where possible, by the same elements as are used in the data base. In terms of the population model, therefore, the out-migrants are subtracted from the data base, and then the in-migrants are added. But because of the very strong interconnection between migration and housing, the path by which this simple addition and subtraction takes place is in fact much more complex. First, when the out-migrants are removed from the population data base, an accounting procedure modifies the stock-occupancy matrix in the housing model to account for vacancies. Although the in-migrants are added directly to the

Figure 1. Framework for interinstitutional and public involvement.

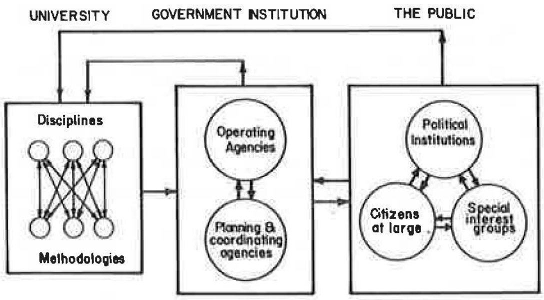


Figure 2. Framework for model refinement, policy evolution, and public involvement.

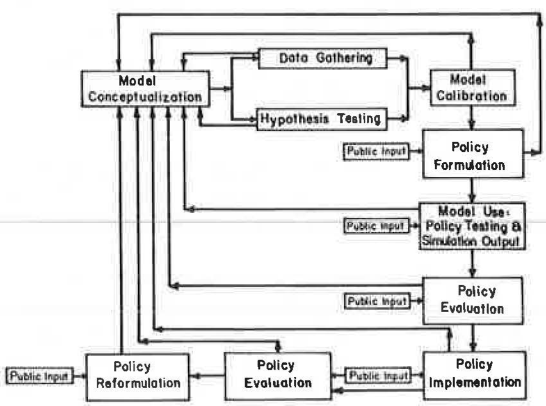
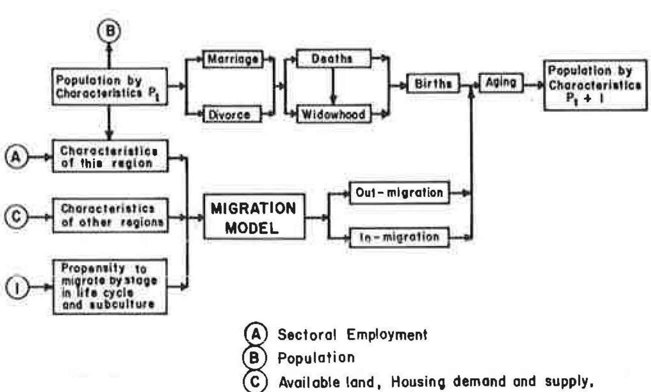


Figure 3. Population model.



population, the annual in-migration, by characteristics, is held for 1 year as an input to the next housing market. This is done to simulate the effects of the housing search characteristic of migrants (19). The final operation of the population model for each iteration is to age the population 1 year by adding one to each element of the age index in the data base.

ECONOMIC MODEL

The regional economy is being modeled with the use of two separate but closely linked models. Figure 4 shows the economic model, which includes an input-output component that calculates gross regional product. The input-output model also yields forecasts of employment in each of the 27 economic sectors into which the economy has been divided.

However, the input-output framework requires estimates of final demand by final demand category for each sector. These estimates are provided by a regional simulation model. The simulation model links the input-output model dynamically to the other components of the module.

Input-output analysis provides a systems approach to the economy (26). In the input-output model, all sectors of the economy are linked. Thus a change in any one sector affects not only itself and its immediate suppliers and buyers but potentially all of the other sectors as well. The input-output model developed here comprises 27 endogenous economic sectors and 9 exogenous or final demand sectors. The strength of the technique lies in the model's ability to link the sectors and their final demands. It is thus an ideal framework for evaluating the impact of changes in one or more sectors on the regional economy. Unfortunately, input-output models are less than ideal for forecasting purposes (4). To be useful for forecasting, an economic model should have reasonably stable parameters over time, or in lieu of stability there should be some satisfactory method for changing the parameters dynamically. Neither of these properties holds in input-output analysis. In addition, even if the model's parameters were stable over time, the model still requires forecasts of final demands to be supplied exogenously.

The simulation model shown in Figure 4 attempts to overcome these weaknesses of the input-output approach by providing first a means of calculating final demands into the future and second a framework for systematically changing the input-output coefficients dynamically.

A simple Keynesian model provides the conceptual basis for the simulation model. The Keynesian model encompasses all of the nine final demand categories. In the aggregate they appear in the familiar national or regional accounting form as $GRP = C + I + G + E$. The simulation model further disaggregates government expenditures into local, provincial, and federal and investment into residential construction and business expenditures on plant and equipment. The other final demand sectors are export categories that are classified according to designation into those related to the rest of British Columbia, the rest of Canada, the United states, and the rest of the world.

The simulation model in turn must generate 27 separate final demands for each final sector, one for each of the 27 economic sectors of the input-output model. The principal variables used to generate these final demand estimates are gross regional product from the previous period, disposable income, population and previous period consumption, investment, government spending, and exports. The resulting final demand forecasts are then supplied to the input-output model to yield gross total output for each of the 27 sectors.

These group outputs can be transformed into employment with the use of employment coefficients that measure man-hours of employment in a sector per dollar of gross output of that sector. Gross output changes that result from changes in final demands (or from any other source) can be converted into employment. It is these employment estimates that are of direct interest to the land use and population components of the module.

Finally, we are currently developing means of changing the input-output and simulation model coefficients dynamically. Phenomena such as new firm location in the region and the related correlate of import substitution are important factors in the change in the technical coefficients through time. The simulation model and the population and land use components can jointly provide some of the required information to model these phenomena and their impact on the input-output coefficients.

In a similar vein, changes can be anticipated in the simulation model coefficients. For example, in the simulation model equation for consumption, it is only reasonable to expect that the coefficient relating disposable income to consumption will change over time, most likely in response to changes in disposable income. Thus, as disposable income increases, the percentage spent on consumption is likely to decrease. In other words, the disposable income coefficient is likely to fall as disposable income rises. Similar dynamic mechanisms have been identified for a majority of the final demand simulation's parameters.

We believe that, by combining the input-output and simulation techniques, we will be in a position to develop more flexible and dynamic models than those constructed previously. In addition, by embedding these economic models in a broader, more powerful simulation module, we hope to create a more useful and realistic regional model for testing economic policy.

LAND USE AND HOUSING MODELS

The land use models are the principal means by which economic activities and popuation are located spatially in the module. The spatial unit used initially is a traffic zone. There are 82 such zones, each an aggregate of census tracts, covering the region. Figure 5 shows the elements of the land use models and their interaction. The principal components are discussed briefly in the following subsections.

Employment Location Submodels

Employment in each of 27 industry groups is allocated on the basis of the locational criteria of each industry. However, there are regularities in the way certain groups of employment choose locations within metropolitan areas; as a result, employment location was further broken down.

Manufacturing and Wholesaling—Employment activities involving manufacturing and wholesaling are disaggregated into major industrial sectors. Employment is allocated to a zone on the basis of its attractiveness to a given industry, where the attractiveness is given by a weighted sum of site factors. The site factors vary from zone to zone, whereas the weights vary from industry to industry. These attractiveness indexes, however, are only calculated for those zones with industrially zoned land and with certain essential factors that each industry must have, such as deep-water access for petroleum refining and railroad access for wholesaling, warehousing, and storage. The indexes are then normalized to allocate net increments to employment as well as employment that is being relocated within the region (29). The allocated employment is converted to land use via a land absorption coefficient (LAC) for each industry. If sufficient land is lacking, excesses are reallocated (8). An index of excess demand for land is calculated to provide a natural feedback link with the economic model.

Because the module is policy-oriented, a range of policies is testable in each submodel. In these initial manufacturing location models, policies available for testing are rezoning of land either to or from industrial use, exogenous removal or location of any desired number of employees of industry group, change in the rights for attractiveness indexes, change in the essential factors, and changes in the values of the site attributes. Each of these policies can be specified for a given time period and for a given traffic zone. This holds true for all of the policies in the study.

Retail Trade—Retail employment is allocated using either of two well-known approaches: the gravity model (13, 20) or the intervening-opportunities model (24, 38). Two alternatives are being estimated and experimented with to determine which is most easily used.

Both of these models generate measures of potential demand for retail trade in a zone. These potential demands are then compared with actual trade in each zone.

Excesses and deficits are not allocated instantly but rather phased in over time. Thus, if there is a large negative difference between potential demand and actual demand, only a part of this deficit is moved from the zone in each time period. This is intended to account for the lags and inertia that occur in practice.

As before, the newly allocated employment is converted to land use via the appropriate LAC. If too much land is found to be required, excess employment is reallocated to areas with adequate land supplies. An index of excess employment is also kept there to feed back to the economic component. Policy interventions analogous to those already mentioned are also an integral part of the retail location model.

Services—To date little work has been done in the area of service employment location. There is a paucity of work on office location (5, 12). Other services have been virtually ignored (36). In this absence of extant research, we are attempting to calibrate the gravity and intervening-opportunity models to provide estimates of service location. Thus, service allocations will be carried out in a manner analogous to retail trade as previously described.

Agriculture, Forestry, and Fishing—The primary activities have not been able to compete successfully for land with urban uses. As a result, these activities are seen as providing potential supplies of land for urban development on the urban fringe. Agriculture, forestry, and fishing are experiencing a decline in the region, and the assumption that these declines allow for conversion to urban land uses is consistent with the idea that they are a significant supply element for urban growth.

Housing Models

Housing policies are certainly among the most interesting, and the housing model can handle policies on renewal, rent subsidy, and receiving among others. To achieve this policy orientation, the present housing models allocate forecast increases in households (population) to each of the 82 traffic zones for each of 15 different types of housing (i.e., three structure types and five value classes). The structure types really correspond to densities and are roughly equivalent to single-family housing, row housing or garden apartments, and medium-rise and high-rise apartments. The value classes are class I, more than \$400 per month rental equivalent; class II, \$200 to \$400; class III, \$101 to \$200; class IV, \$51 to \$100; and class V, less than \$50.

The rental equivalent is intended to eliminate problems in tenure determination in the model and reduces all housing costs to a common base. The housing model proceeds by converting population into demand $D_j^{i,k}$ of structure type k, value class i, in subarea j. This demand is determined by using information from the population model on family size and the age structure of the population and information from the economic model on income distribution. Subarea attributes such as the types and quantities of housing already present in the zone, accessibility of the zone, and slope and amenity characteristics shape the spatial distribution of demand. Supply is determined in a similar manner. Initially, however, supply is constrained to be equal to demand at the regional level. Differences between $S_j^{i,k}$ and $D_j^{i,k}$ not only are permitted but in fact are the principal market forces underlying the housing location model. The zonal supply and its breakdown by structure type and value class are determined by zonal characteristics such as accessibility, availability of land, allowable and actual densities, and the excess supply from the previous iteration of the model. Most location models have lacked any model of the market mechanism (15, 31).

Supply and demand are reconciled through a simple market resolution process that cumulates excess demand in each zone and allocates it to zones with excess supply. Where housing of the wrong structure type and value class is all that remains, the number of units filled with potentially dissatisfied residents is noted and excess demand is allocated to these units. The index of dissatisfaction that results is a prime force in the market adjustment in future periods. Finally, the housing units are converted to land use, and the model begins its next iteration.

Recreation and Open-Space Models

At the present time, recreation and open-space determination is carried out in an extremely simplistic fashion. Two different kinds of parklands are identified: local and neighborhood parks and regional parks. For each there is a 5 by 3 matrix of park-land absorption coefficients, one for each value class and structure type of housing. These two land absorption matrices represent current planning practice and are subject to change for policy testing purposes. They are used to calculate the number of acres of local and regional parks required to serve the forecast increases in population. The required land is taken from each subarea (traffic zone) and from the urban periphery.

THE MODULE: THE COMPONENTS AND THEIR INTERACTION

The previous sections briefly described the component population, economic, and land use models. Figure 6 combines these models in a somewhat abbreviated form to illustrate the links among the models. The links described here are the simplest and most direct links. More complex links will be identified as the models are refined and take on greater complexity. The process of identifying, programming, refining, and extending links is identical to that followed for the model separately, and the module as a whole is discussed in the conclusion at greater length.

For expository purposes, the links will be summarized as those between population and economics, population and land use, and economics and land use.

Population and Economics

In each link, the interaction between the pair of models is two-way. In the present case, population supplies economics with the migration and total population information needed by the simulation portion of the economic model. Economic information on employment, income, and gross regional produce flows to the population component from the economic model. There is a one-period lag in these flows. Thus, population receives employment information in period t to calculate period t+1 total population. This population for t+1 is used to calculate final demands in t+1, which in turn is used for estimating t+1 employment.

Land Use and Population

Land use needs an estimate of the increase in the number of households each period. This information comes from population and directly affects the housing component of the land use model. Population increase in period t is used to calculate housing requirements and use in the same period. However, housing and land use relate to population for use in calculating migration in period t+1. Once again the flows are in two directions with a one-period lag.

Land Use and Economics

In order to forecast the location of economic activity in the future, the land use models require a regional forecast of activity by industry groups. The economic model has as its primary output forecasts of employment increases and decreases for the region for each of the 27 industry groups. The land use model then distributes these spatially. Employment forecasts for period t are used to generate employment location for period t. However, land use also provides the economic model with information on the availability of industrial and commercial land. This is used in the simulation model of final demands. Available land and density information for period t from the land use models is used by the economic model for its forecast of economic activity in period t+1, once more a two-way flow with a one-period lag.

These links, as noted earlier, are the simplest and represent the first stage in the evolution of more complex and realistic links among the component models. Thus, at a later date, information on recreation and open-space land along with estimates of land prices or scarcity may be incorporated into the migration model as more detailed information on regional characteristics. Similarly, information on agglomeration and spatial association might be included in the simulation model to change the input-output coefficients dynamically with changes in spatial links among sectors within the region. Other links will be identified and tested in the continuing process of evolution and refinement to which the models and the module are being subjected.

Figure 4. Economic model.

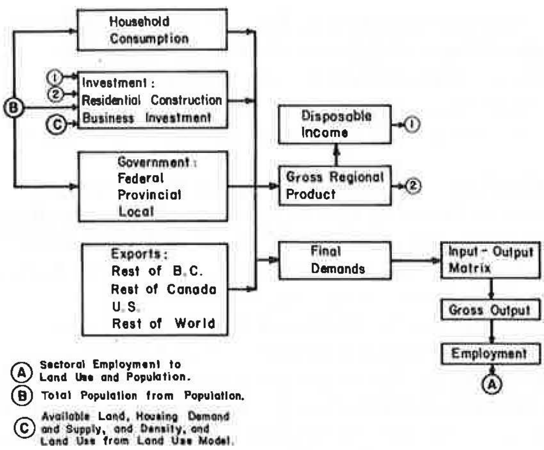


Figure 5. Land use model.

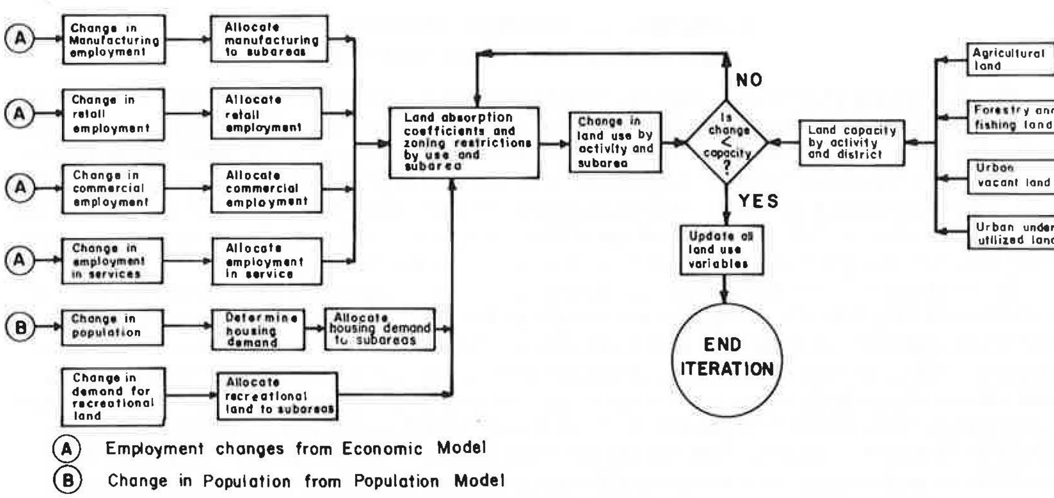
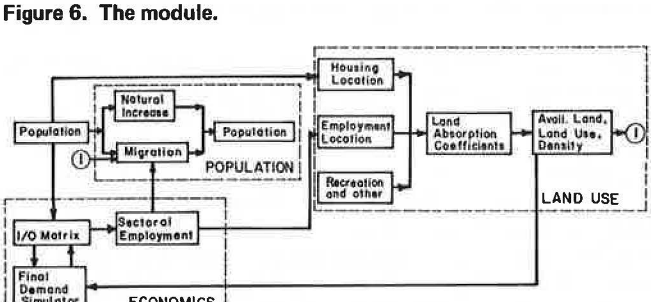


Figure 6. The module.



CURRENT PROGRESS

As of this writing, work is well along in the development of the module. The basic cohort-parity model is programmed and operational with a simple trend migration component. A more advanced version of the natural increase submodel and a much more complex migration model have been conceptualized. Much of the information has been gathered, and both submodels are in the process of being outlined (in flow charts) and programmed.

Work on the economic model is not so advanced. A sample of 3,800 firms has received input-output questionnaries. Based on returns from this sample an input-output table will be built, with a completion date of late summer 1973. The simulation model for the final demand matrix has been conceptualized and programmed. This also is expected to be completely debugged and calibrated by next summer.

Finally, the land use models as described here are fully operational. They currently receive inputs from the population model and from a simple trend economic model. Work is currently in progress to develop the feedback links from land use back to the population and economic components as described in the preceding section. Simple two-way feedbacks among these models are expected to be programmed and running by early spring 1973. By late 1973, the final versions of all these models should be fully operational with the completion of the input-output simulation model of the regional economy and the behavioral model of migration.

REFINING, APPLYING, UPDATING, AND EXTENDING THE MODULE

The foregoing provides a capsule description of the module that we are in the process of developing. Following is a sketch of the strategy for continued evolution of the module. Because a critical element in this evolutionary process is the application of the module, stress is placed on likely uses to which the module can and hopefully will be put. Only through a series of applications of this simulation framework do we see the means for updating the models and identifying their strengths and weaknesses so that they can be extended and refined to meet unfulfilled needs.

In the approach we are following, refinement, use, and extension of the module are not strictly separable. They are elements in the model development process that subsume continuous evolution and refinement of the module. Thus, each of the component models is conceptualized, programmed, calibrated, and refined separately, and where necessary whole subcomponents are replaced as more useful elements are developed. The three components are then interfaced to form the module, which is itself refined as an entity quite separate from its three components. Although this activity is occurring, new components are being developed to replace existing ones. Application of the module is continually kept in mind so that the module that evolves through changes in its parts and their interaction will have the broadest possible application and greatest ease of interfacing with other models, such as those dealing with transportation and pollution.

This brings us to questions of use. The greatest potential area for application is in urban transportation planning. Transportation planning has been responsible for creating some of the most useful computer simulation models of urban systems. In addition, the transportation models that are currently in operation have a substantial requirement for spatially disaggregated economic and population data. The module previously described is designed to provide such output. In addition, one of the principal outputs from transportation models is a matrix of time distances among spatial units in a region. This matrix, in turn, is one of the prime data needs of the land use component of the module. As a result, the module and transportation models have several natural feedback links. By linking the module with a transportation model, the effects of land use policies on transportation systems could be examined as well as the effects of transportation plans and policy on land use (39).

Just as there exist certain natural points for interfacing the module with a transportation model, so do there exist other natural interfaces with a variety of environmental models (3). It is pointless, without specific example, to go into the details of these other applications of the module. The procedure, however, is straightforward and would be as follows. The interfacing problem is reduced to one of bringing the module designers together with the designers of the using model. Interfacing therefore reduces to a bilateral negotiation between the supplying model and the receiving model. For some data the module will be the supplying element, whereas for others (as with the time distance noted previously) the module is the receiving element. In general, receiving elements desire greater detail and precision than applying elements can deliver. There is overlap, though, between the area of minimum detail acceptable to the receiving component and the maximum possible detail that the supplying model can provide. The final level of requested and supplied detail is the result of this bilateral discussion procedure. This bilateral procedure has already been followed with considerable success, and there is every reason to believe that both the procedure and the module have quite widespread applicability.

In the final analysis, however, usability is the ultimate criterion on which any simulation must be judged. The module must be useful, usable, and, above all, used. The usefulness of the module depends very much on the inclusion of those variables, parameters, and policies that are affected by and in turn affect real-world policy-makers and citizens. Cooperation from government officials and citizens is imperative for identifying those variables and policies that are of direct importance to governments and residents of the region being modeled. In Vancouver, we have direct ties to all levels of government as well as a variety of activities that are designed to provide citizen input to the work.

The module must also be usable. It must be economical of machine time, reasonably easy to understand, straightforward to operate, and, most importantly, accessible to all interested individuals.

Finally, in practice, to be useful and usable, models must be used. Use cannot be restricted to specialists in the planning field, but rather the module must be open to all. Looking at other modeling efforts, it seems clear that these use criteria have not been fulfilled or perhaps even sought.

CONCLUSIONS

The idea we have stressed throughout has been that of a model building process. The process is the essence of the approach, the product (the models) merely a means toward that end.

It is imperative that models and model building be subjugated to the process. The process is dynamic and open-ended. It is constantly changing its goals and objectives. Products on the other hand have in the past been institutionalized when successful. Enshrining our technology in institutions allows it to become static, to become an end in itself instead of a means to a more dynamic and global end, such as better planning for a more livable, diverse, and pleasant urban environment.

Success is to be feared more than failure. Failures vanish and cease to influence our society; successes live on. They grow and build on each other and become perpetuated, primarily because of past successes. Agencies like the Tennessee Valley Authority (originally a conservation agency) have lost sight of their initial broad objectives and have been carried away by a series of narrower achievements. In the TVA case, we find that agency currently one of the prinicpal users of strip-mined coal in the Appalachian region that it was originally created to protect.

The longest-surviving human societies have learned above all to live with success. They have succeeded where we have failed because of a skepticism about innovation for the sake of innovation (37). We are suggesting the same sort of critical assessment of our activities. The dangers of blind acceptance of simulation models (or any other technology) in our opinion outweigh the benefits. Models can too easily yield self-fulfilling forecasts. They can be put in a position of justifying actions rather than assessing likely consequences.

Direct public involvement holds promise of providing a way out of the positive feedback of self-serving success. Only through public communication can model builders and users jointly identify weaknesses and limitations of the models. The weaknesses are more importantly stressed than the strengths, as the strengths are usually sufficiently overwhelming as to jade the user's vision and lead to the dangerous state of blind acceptance.

The public is the key. Widespread diffusion of the model building process has the potential to keep models in perspective and above all in the service of people. The public is the ultimate safeguard against institutionalized, uncritical, and self-serving applications of models and model building to urban planning.

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