ON THE USE OF THE GARIN-LOWRY ACTIVITY ALLOCATION MODEL IN METROPOLITAN AREA PLANNING: THE CASE OF WINNIPEG

by

Robert J. Crews

A Thesis

submitted to the Faculty of Graduate Studies

in partial fulfillment

of the requirements

for the degree

of

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ABSTRACT

The current debate concerning the potential utility of large-scale, quantitative simulation models to the predicting of urban development processes is familiar to urban planners and analysts alike. This research examines the operation of the Garin-Lowry activity allocation model, and its ability to describe the structure of the Winnipeg urban system for a 'base-year' of 1971. A doubly-constrained gravity submodel is used to simulate work and shopping-trip behaviours as the foundations for the allocation of employment and population to subareas of the bounded metropolitan spatial landscape. A second economic base submodel is operated on functional-economic criteria via the minimum requirements technique. The zone system partitions the landscape into 9 superzones and 125 zones whereupon spatial resolution is increased relative to other similar research on the model; this design then constitutes a comparatively rigorous test of the model's capabilities.

The definition of the economic base, and the sensitivity of the associated multiplier, are found to be vital determinants of model performance. Winnipeg's spatial isolatedness and the nature of its role as regional service centre, introduce certain unique elements into the 'base' concept wherein the criticality of manufacturing, transportation, financing, and administrative functions to the metropolitan economy is suggested. Although the minimum requirements technique derives the most conceptually satisfying description of the base, the associated subdivision of individual industrial sectors into

basic and service components is largely incompatible with the nature of the interaction data governing the internal allocation of employment.

It is suggested that the economic base be realigned in accordance with a method, on either functional or locational criteria, wherein individual sectors are wholly classified as basic or service. This would be proved the most immediately fruitful means of effecting improvement on the comparatively poor correspondence in activity distributions derived in this case.

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Models are undeniably beautiful, and a man may justly be proud to be seen in their company. But they may have their hidden vices. The question is, after all, not only whether they are good to look at, but whether we can live happily with them.

(Kaplan, 1964:288)

CHAPTER ONE - INTRODUCTION

A plethora of new methods in the analysis of urban systems have been employed in geography in recent years, many of which are based on analogies with other disciplines, especially the more advanced sciences. This constitutes a shift from the view of geography as essentially descriptive scholarship and interpretation to a view which recognizes the need to explain phenomena of interest by building theories and models, and ultimately to develop a predictive capability. In such fields as urban and regional planning, there has been generated a substantial demand for predictive capability which in turn, makes increasing demands on geography both as an essentially synthesizing discipline and as the only discipline which makes a direct attack on spatial analysis. This all adds to the pressure to produce theories and models which can assist prediction (Wilson,1969B:5).

An important aspect of the new methodology is the development of comprehensive activity allocation models. The allocation of activities to subareas of a bounded region is an important aspect of urban modelling as it provides major inputs to land use and transportation planning and in addition, it offers a means through which changes in the urban system can be better monitored and understood (Batty, 1971). Apart from using these models for evaluating change in spatial systems, it is important to recognize that any urban model is a translation of an hypothesis about the organization of the urban system into a form which can be manipulated and tested against observations in the real world (Harper, 1973:63).

This research examines one activity allocation model originally developed by Lowry (1964) and modified by Garin (1966) as it applies to Metropolitan Winnipeg. Emphasis is placed on considerations in model preparation and internal methodology towards maximizing the model's description of the Winnipeg urban system for 1971.

1.2: Literature Review and Research Objective

The model structure is comprised by an economic base submodel for determining total employment and population levels, and a gravity-type submodel for determining the probability of inter-zonal interaction with respect to workplace to residence, and residence to 'service' facility allocation. The framework has been developed and used extensively in the United Kingdom and North America at both the regional and metropolitan scales of enquiry. Its role within the planning function is visualized as one of many facets, including 1.) impact analyses, wherein model input variables are manipulated to reflect alternative economic policy or structural design alternatives, 2.) the continuous use of the framework as a means of monitoring the strengths and weaknesses of existing programmes, 3.) its use as an exploratory tool in the generation of alternatives as a primary planning exercise, and 4.) its use as an educational tool whereby the planner's and decision-maker's knowledge and awareness of system behaviour is heightened. In short, urban models should be capable of generating insights into the functioning of spatial systems as well as providing a means for simulating urban phenomena (Batty, 1976:233). It is also evident however, that they should be used with caution, until they are fully tested and justified empirically (Reif, 1974:45).

> In choosing a model to use in a particular study area, it will of course be necessary to ensure that the model can provide a 'reasonably' accurate description, and forecast, of the relationships and interdependencies of reality (Massey, 1973:11).

The first stage of the model evaluation process concerns a test of the model's capabilities to adequately describe the system under consideration. The specific objectives applying in this case then include the investigation of 1.) data base requirements, in relation to the availability and form of information from existing sources as the compiling and/or realigning of data are factors in the convenience and cost of model preparation, 2.) the relationship between zone system design and 'base-year' goodness-of-fit, 3.) the operational consequences deriving from alternative definitions of the economic base within the model, and

4.) problematic issues in the measurement of goodness-of-fit between empirical and model-generated activity destributions.

1.3: Organization

Chapter two begins with an introduction to the model concept and the perceived roles of quantitative models and the scientific method in relation to urban spatial analysis. The structure of the original Lowry model is then presented so as to introduce the 'parent' framework from which the Garin model is derived. The chapter closes with the presentation of the Garin derivative wherein its theoretical and practical strengths and weaknesses are contrasted to alternative modelling techniques.

Chapter three presents a survey of the related literature. This section begins with a definition of the planning function and a summary of the visualized roles of simulation models therein. The discussion then focuses on the proposed utility of the Garin model in prediction and policy-making with selected North American and British examples. The remainder of the chapter deals specifically with the objectives of this research in relation to Metropolitan Winnipeg.

Chapter four deals entirely with the procedure of preparing the data base and computer package. The chapter opens with a discussion of problematic issues in the acquisition and alignment of data for purposes in the model. This is followed by an account of the gravity model and interaction data adopted for purposes here from the 1971 Winnipeg Area Transportation Study; this model is contrasted to the Garin interaction submodel and relative strengths discussed. The economic base analysis of the metropolitan economy follows with an investigation into alternative methods. The chapter closes with a brief description of the computer package.

Chapter five presents the results of model trials wherein the best-fit distributions of employment and population possible in this case are discussed and tested for goodness-of-fit. Apparent strengths and weaknesses in both the data and correspondence measures are related to data form, zone system design, and economic base methodology.

Chapter six summarizes the findings and provides a discussion of some of their implications. Finally, some fruitful avenues for possible future research are suggested.

One further aspect of this research should be recognized. This research does not constitute an examination of the model in its fullest capacity; such an undertaking would exceed all practical constraints. Data and other budgets necessitate the adoption of inflexible sets of interaction data for use on the model in this case. In other similar research, it is common for improvements in the allocation of activities to be approached through the interaction data as part of a second-stage calibration procedure. As this option is not available, the final product here represents a comparatively crude form of the model. As such, this research is perhaps best considered as a first exploratory stage in evaluating the model's potential in metropolitan area planning for the case of Winnipeg.

CHAPTER TWO:

INTRODUCTION TO THE MODEL

2.1: The Model Concept

Among the offspring of the quantitative revolution of the 1960's, a period of heightened emphasis on methods of statistical mechanics in social science research, was a substantial body of highly sophisticated mathematical models, new tools for the interpretation of various theories of urban spatial structure.

The central theme of this development was one of 'generalization' or 'idealization' – the reduction of the many inherent complexities of urban form to the more manageable laws of common algebra. This generalization process was considered the 'bridge by which the scientist or theoretician crossed over from induction, or the observation of reality, to deduction, or the testing of theories and their application to new phenomena' (Harris,1966:262). In a different light, this implied a consonant shift from what, until then, were primarily descriptive theories, to operational, analytical, and most noteably predictive tecniques. The challenge of model development, itself a response to a realized need for greater analytical capability in planning and research, is best summarized by Harris:

> ...there are difficulties of identification and classification of concepts, difficulties in detecting regularities, and consequently insurmountable difficulties in devising hypotheses which genuinely produce regularities as deductive consequences. Nevertheless, a scientific approach can be adopted ... It consists of the breakdown of the complex system into manageable components or subsystems to provide an analytical framework. This framework is a tentative first step in the search for

> order and itself represents a degree of explanation. Attention is then directed to the causal relationships (interdependencies or interaction) observed within and between subsystems. (Harris,1966:121)

Since their initiation, models have been attributed multiple definitions yet no attempt would be complete without first clarifying the vital relationship between any model and its parent theory;

> The construction of a model presupposes the use of a theory which explains parts or the whole of the relationships established in the model. Consequently, the predictions and solutions derived from the model are deduced consequences of the theory.
> (Rief,1973:49)

A theory may be considered a well tested hypothesis or more explicitly, a logical (or mathematical) law or set of statements of very high probability characterizing the phenomena or variables to which it refers whereas a model, is an experimental design based on a theory; that is, all laws are models but not all models are laws(Chorley and Haggett,1967:24,Harris,1966:265). There are two possible styles of approach to the development of such models; the hypotheticodeductive approach (building a model and testing the predictions against observations, as the example considered in this research), or the inductive approach (starting with data and attempting to infer general laws) (Wilson,1974:4). Regardless, all models are ultimately low-variety representations of high-variety situations, a view perhaps most cogently described by Chorley and Haggett:

> A model is thus a simplified structuring of reality which presents supposedly significant features or realationships in a generalized form. Models are highly subjective approximations in that they do not include all associated observations or measurements, but as such they are valuable in obscuring incidental detail and in allowing fundamental aspects of reality to appear. This selectivity means that models have varying degrees of probability and a limited range of conditions over which they apply. The most successful models possess a high probability of application and a wide range of conditions in which they seem appropriate.
>
> (Chorley and Haggett, 1967:22)

2.2: The Functions of Models

The predictive function of models has already been commented on; other functions of such models, according to a more universalistic view of such research, include:

a) a psychological or educational function, in enabling some group of phenomena to be visualized and comprehended which could otherwise not be because of its magnitude or complexity,

b) an acquisitive and organizational function, in that the model provides a framework wherein information may be defined, collected, and ordered,

c) a fertility function, in allowing the maximum amount of information to be extracted from the data,

d) a logical or explanatory function, by helping to explain the origin of particular phenomenon,

e) a systematic function, wherein reality is viewed in terms of interlocking systems,

f) a constructional function, in that they form stepping stones to the building of theories and laws,

g) a normative function, by comparing some phenomenon with a more familiar one,

h) a cognative function, by promoting the communication of scientific ideas; "the idea is nothing till it has found expression" (Kaplan, 1964:269) (Chorley and Haggett,1967:24-5).

2.3: The Conventional Lowry Model

The Garin-Lowry framework represents the second generation of a family of urban activity allocation models evolving from Ira Lowry's 'Model of Metropolis' 1962-3. The original model was developed in the U.S.A. as part of a modelling system to generate alternatives and aid decision-making in the Pittsburgh Comprehensive Renewal Programme (CRP), wherein Lowry's intended purpose was "the development of an analytical model capable of assigning urban activities to subareas of a bounded region in accordance with those principles of locational interdependence that could be reduced to quantitative form" (Rief,1973:170). The salient components of urban spatial structure represented in the model comprise three groups of activities; 1.) a Basic sector, including industrial, business, and administrative activities whose locations are assumed to be unconstrained by local circumstances of population distribution, market areas, and so on, (hence the employment level and location in the basic sector must be assumed as 'given', and so determined outside the model); 2.) a Retail or Service sector, including all those activities dependent directly on local resident population and purchasing power; that is, all activities for which a local market or service area can be identified for 'final' products and services, (the employment levels and locations in this sector are treated as endogenous variables whose values are determined inside the model), and 3.) a Household sector, consisting of the resident population on which the retail sector depends and which itself depends on the total employment level (basic and service) available, (it is assumed that the location of households is powerfully influenced by the distribution of employment; thus both population size and distribution are also endogenous)(Reif,1973:171).[1]

Both land use and interactions between land uses are considered. The theory underlying the framework identifies population and service employment as the critical activity variables, and movements between workplace and residential areas, and between residential areas and service centres as the critical interaction variables(Batty,1970:308).

1. Hereafter, the terms 'retail' and 'service' are considered synomonous in reference to this model sector.

Total employment in the study area is partitioned into two sectors, basic and service, implying some foundation in economic base theory. It is assumed that, given the distribution of employment in the basic sector, service employment and population can be derived;[2] that is, the distributions of population and service employment are consistent with the distribution of basic employment. Besides deriving the levels of the dependent variables, the model allocates these activities to different zones of the system (Batty,1970:308), on the basis of a zonal score or value of residential and/or service centre potential in accordance with two sets of activity constraints; one governing maximum population densities and the other, minimum threshold sizes for service functions. Thus the spatial system may consist of four types of zones; 1.) unconstrained, 2.) population constrained, 3.) service constrained, or 4.) both in the same zone (Batty,1976:57).

Once the distribution of basic employment is specified, the model first determines the residential locations of these workers and the associated level and distribution of population by application of a system structural multiplier, an inverse activity-rate.[3] The first increment of service employment is then derived from this basic population using the second structural multiplier, a population-

---

2. Thus, in the economic base mechanism, basic employment acts as the primary independent variable with population and service employment as the associated dependent variables.
3. The inverse is used since population is derived from employment allocated to residential zones.

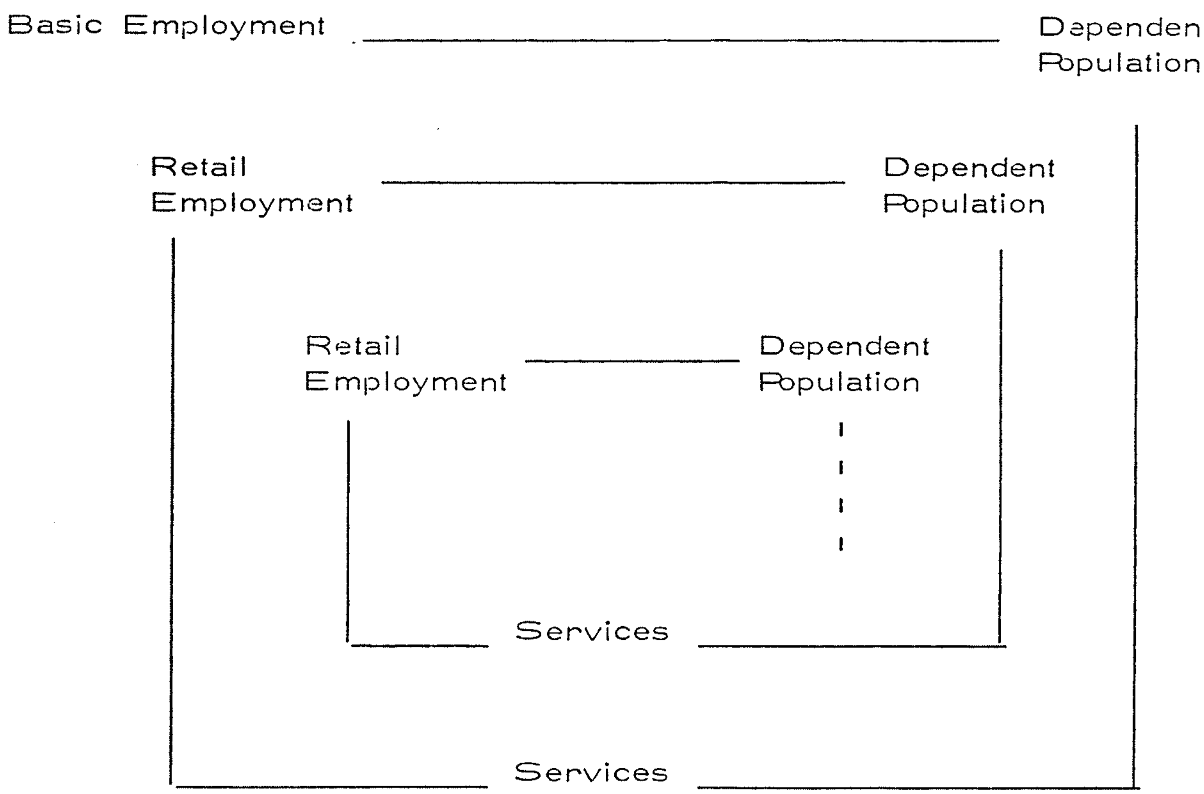
serving ratio (a ratio of service employment to total associated patron population), and this employment is allocated to service centres (Batty,1970:308). These workers require residential locations , thus leading to an additional increment of population and in turn, to a further increment of service employment and so on (Figure One). Continued application of this iterative sequence results in the derivation of successively smaller increments of service employment and associated population to some threshold, below which any added incremental values are negligable. The process is then said to have converged (Batty,1970:308).

Lowry developed a sophisticated structural housing for his functional subsystems which included; 1.) a full land accounting system on a per zonal basis for purposes of monitoring land consumption by land use type at the conclusion of each iteration of the model, 2.) the inclusion of an additional 'potential' submodel describing workplace to service activity interaction, 3.) several options for the disaggregation of households, in varying degrees, according to income group, housing type, and availability by location, 4.) similar options for the disaggregation of the service sector by activity type or employment, 5.) the incorporation of two sets of constraint procedures, one representing maximum population densities in residential zones and the other, minimum threshold sizes for service activities in specific zones, and 6.) a consistency-checking

Figure One:

CAUSAL AND FUNCTIONAL STRUCTURES OF THE LOWRY MODEL

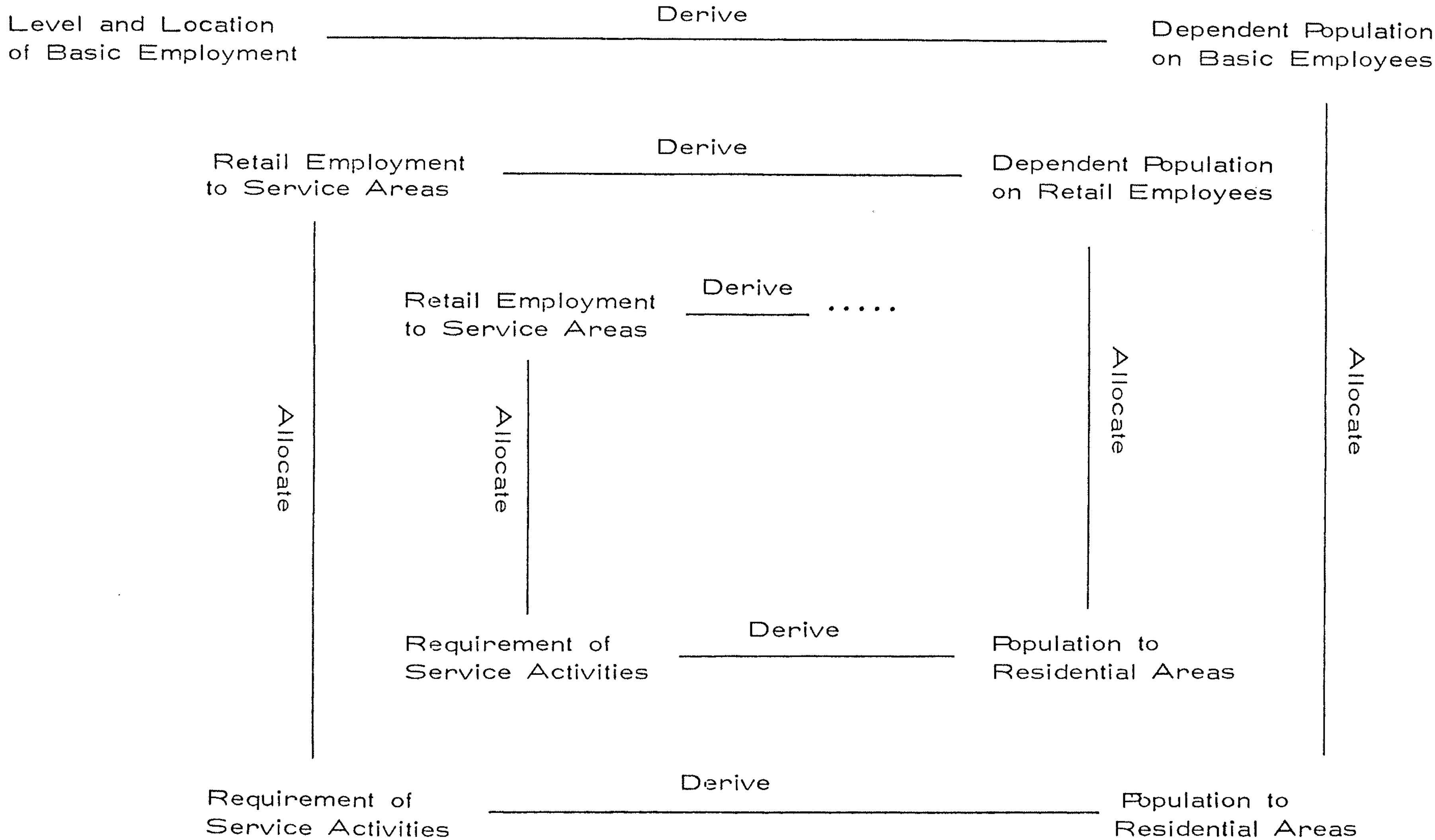
CAUSAL STRUCTURE



Source: (Reif, 1973:176)

Figure One:

FUNCTIONAL STRUCTURE



Source: (Reif,1973:177)

device to assure level similarity in the dependent variables at the input and output stages.[4]

Where the above represent issues of structure and spatial aggregation, a further issue of modelling technique - the treatment of time - must be highlighted in relation to Lowry's model since this is a critical determinant of (and is determined by) both the purpose and potential value of the modelling approach;

> ...the important 'time' question relates to whether the model-builder is attempting to represent the total cross-section of one or more activities at some point(s) in time, or the marginal change between two points in time. This turns out to have a fundamental bearing on technique. The perfect answer to the question would be to seek a fully dynamic model in which 'time' was a continuous variable which had been applied over a very long time period so that both cross-sections and marginal changes were predicted by the model. This is rarely possible in practice...
>
> (Wilson, 1974:172)

Time can be treated in three ways; implicitly, explicitly and discretely, or explicitly and continuously (Wilson, 1968:260). It must be made clear that there is no dynamic element included in the framework; the model solution defines a static equilibrium of the dependent variables service employment and population, related to and as a direct function of the specified level of basic employment provided as an input. As such, the forecast level and distribution of basic employment serve to implicitly represent the time dimension

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4. Several of these options are retained in more recent derivative forms attributable to other authors.

as the foundations of an 'instant metropolis', thought to characterize the system state in the horizon year. As the distributions of the dependent variables are included in model output and, more importantly, since these distributions are products of a simple 'one-shot' forecast,[5] any attempt at cross-sectional analysis is limited to only two points of reference where, (as is commonly the case), the corresponding time series data are not available. An indication of marginal change in the level of activity is provided at the spatial scale selected by the researcher. The rationale underlying the static equilibrium approach is addressed in the following contention;

> If we believe that the system is an equilibrium system, then (we) can attempt to build a model of the static picture; that is, to relate and explain the variable at one point in time without 'time' appearing as an explicit variable. (Wilson,1974:25)

It seems clear that the 'time' issue in model design in this case, is conveniently solved by the equilibrium assumption, thereby justifying the use of the basic employment term as proxy. It also seems clear however, that this justification is only one of model design - it has no empirical foundation.

The second primary consideration regarding technique relates to the algebraic notation developed to represent theory in operative form.

---

5. This phrase refers to the specification of one time horizon. In updated model forms, a recursive format is used wherein the input requirements for each of a series of runs are computed internally from the output of preceeding iterations. As this was not a feature of the conventional model, it will not be considered here.

Algebraic models express relationships between variables using the operations of elementary algebra coupled with the notion of a 'function' (linear, exponential, log, etc.). The relationships may involve notions of causality although this is not necessary (Wilson, 1974: 174). The salient options include;

1.) spatial interaction models, the essence of which lay in the concept that the activity to be located has a strong interaction with some other activity ie. an assumed propensity for service activities to locate with respect to resident population and purchasing power (Wilson, 1974:174). Such models are typically singly-constrained frameworks (production or attraction) where the allocation process may be regulated by exogenous constraints (hence doubly-constrained) or modified with the incorporation of spatial attraction factors to compliment the travel impedance function;

2.) entropy-maximizing models, wherein methods of statistical averaging are used to derive a measure of uncertainty used in information theory which is concerned with the problems of deriving the maximum useful information from a given signal. If the 'given signal' is considered to be the data which partially describe the urban system, information theory provides a framework for analyzing the data in such a way as to extract from them the least biased description of the state of the urban system as a whole (Rief, 1973:70);

3.) matrix operator models, wherein lie the advantages of i.) allowing the accelerated solution of a set of simultaneous linear equations, reflecting both direct and indirect impacts through matrix inversion, and ii.) permitting a more highly resolute representation of spatial structure at the input stage through the use of diagonal matrices for structural multipliers (ie. labour-force activity-rates) of dimension NxN (N= number of zones);

4.) linear programming models, when it is possible to construct an objective function which, when maximized or minimized subject to linear constraints, 'reproduces' behaviour (Wilson,1974:175);

5.) differential or difference equations, which are concerned with change- the period of change being measured by some independent variable - where the variable is continuous in the first case and discrete in the second. In effect, the body of mathematics associated with these concepts enables the proper handling of 'time' (Wilson,1974:175);

6.) algorithms or algorithmic models, wherein the model can be specified as a set of rules which enables numbers to be operated on, though the rules and the consequences of applying them cannot be written down as a set of algebraic equations (Wilson,1974:175). Examples include such procedures as i.) matrix inversion and the corresponding solution of simultaneous linear equations, ii.) the shortest path through a network, iii.) linear programming, iv.) search routines, and v.) multiple regression analysis. As such techniques are often considered methodological 'black-boxes', it is important to know only that the algorithms exist and work, not any detail as to how they work (Wilson,1974:60);

7.) simulation models, wherein the underlying theory consists of a set of statements involving conditional probabilities. Generally, simulation techniques are used for situations too complicated to be handled by more straight-forward algebraic methods (Wilson,1974:175);

8.) econometric models, usually linear and additive and having some basis in economic theory;

9.) economic, ecological, and game-theoretical techniques, essentially products of some of the previous tecniques and constrained by a set of rules from an adopted viewpoint ie. the economist's view of locational analysis based on the theory of consumer behaviour, suitably aggregated (Wilson,1974:176).

The core of the conventional Lowry model consists of two spatial interaction submodels, one governing each of residential and service centre location. The logical structure of the model can be expressed in nine simultaneous equations and three inequalities (Wilson,1974:222), the latter denoting constraints. Variables are identified by the following according to Wilson;

A = area of land

E = employment

P = population

C = trip cost

Z = constraints

Subscript and superscript definitions are as follows;

U = unuseable land

B = basic sector

R = retail sector

H = household sector

K = class of establishment within the service sector

m = number of classes of service establishments

i, j = zones, usually origin zone i, destination zone j[6]

n = number of zones

(Wilson, 1974:221-22)

Land Use

$$A_j^H = A_j - A_j^U - A_j^B - A_j^R \qquad (2.1)$$

This land is considered available for residential use.

Household Sector

$$P = @ \sum_{j=1}^{n} E_j \qquad (2.2)$$

or alternatively, the analytical form of the economic base,

$$P = @ \sum_i E_i^b \left(1 - @ \sum_k \&^k \right)^{-1}$$ where

@ = the inverse activity-rate, and

& = the population-serving ratio, from

6. Since the place of work is considered the 'origin' in the model, with respect to work to home interaction, 'j' represents place of residence.