1. *The art of urban modelling*

The art of urban modelling, which has evolved during the last decade, is part of a much wider revolution in thought within the social sciences, a revolution which began in North America over twenty years ago and which is continuing apace today. In the quest to infuse both rigour and quality into disciplines such as sociology, political science and urban studies, social scientists have turned to fields such as modern physics in the hope that powerful analogies might exist, thus pointing the way to more sophisticated and relevant theories of human behaviour. In the early years of this endeavour, the emphasis was on abstraction in the form of simple theories of social and economic organisation although the importance of testing such theories was quickly realised and the concept of modelling the system and manipulating the model in the hope of gaining new insights became firmly established. Models of social and economic systems involving the essential idea of simplifying reality to a point at which it is understandable hardly embody new ideas, but the formalisation of what was previously implicit involves a realisation that modelling is fundamental to the rigorous development of all the social sciences. It is in fact this realisation which distinguishes modern social science from its ancestry.

The development of urban research which is closely linked to urban modelling is founded upon the conviction that urban phenomena exhibit a degree of complexity which only formal study can hope to unravel. The complexities and ambiguities surrounding the mechanisms sustaining and altering the modern city have become more and more difficult to understand as urban society has become more diverse, more mobile and more diffuse. Thus, urban modelling has developed as a direct response to such complexity although such developments have also been tied to advances in large-scale computation without which urban modelling could never really have begun. Modern theories of the city such as those involving the spatial organisation of land use and related activities and the economic behaviour of different locators in the city require symbolic models in their testing and refinement against real world data; such use of models as media through which the science of urban organisation can be refined and evolved represents the first important role for urban modelling, a role which is a relatively pure expression of the goal involving the search for a greater understanding of urban phenomena.

There is a second and perhaps more fundamental role for urban modelling and this involves the use of urban models in physical planning. Indeed, the short history of urban modelling which is to be outlined in this first chapter suggests that most of the large-scale numerical models already developed in an urban or regional context were based on the notion that better forecasting could only result through their use. In some senses, the two roles for models just outlined are both required in planning studies, and frequently the need to use models in forecasting can be an essential complement to models designed to achieve a better understanding of reality, and the reverse is also true. Most of the models referred to in this book are based on the requirement that such models need to be operational: that these models can be implemented using real data on large-scale computers and can thus be manipulated in both analytical and predictive contexts. This is in contrast to a large number of models which are essentially theoretical in nature, such as those models explaining the structure and behaviour of urban markets. Although these models are critical to the development of computer simulation models, for all intents and purposes in this book, they will be regarded as theories upon which the art of urban modelling is based.

Science and design in urban modelling

The need to produce more coherent and suggestive theories of urban structure and growth has been the prerogative of urban researchers drawn from the fields of urban economics, geography and sociology as well as planning, architecture and engineering. As in most branches of the physical sciences, the development of theory is implicitly based upon the commonly accepted cycle of scientific method involving hypothesis formulation, observation, experiment and hypothesis refinement, tasks which can be and have been carried out in more or less any order. Urban modelling involving the construction of models based on particular hypotheses is largely concerned with the experiment and refinement stages of the cycle in which the theory or hypothesis is translated into a testable form. A most pertinent definition of an urban model formulated by one of the sages of the field, Britton Harris, is based upon this scientific focus. Harris (1966*a*) defines an urban model as 'an experimental design based on a theory', thus recognising the role of modelling in the search for a relevant understanding of urban structure.

Yet it is necessary to dispel the myth that urban modelling and indeed, any branch of scientific endeavour, is mechanistic and technocratic. The popular view of science is based on the notion that science is an inevitable outcome of rigid narrow thinking, but that is far from the truth. Science like any other area of knowledge is largely based upon insights which occur through intuitive processes (Medawar, 1969). Despite Poincaré's dictum that 'discovery favours the prepared mind', many an analysis of the history of science, for example that by Kuhn (1962) described briefly in the introduction, reveals that science does not progress continuously and mechanistically but advances in discrete jumps based on fundamental insights and intuition. The idea of science as a process of conjecture, then refutation of problems, followed by tentative solutions, error-elimination and the redefinition of problems (Popper, 1972) is reflected in the development of urban theories and models as will be illustrated later. But perhaps the most important change which has taken place in the development of urban theory and modelling in the last decade is in the gradual switch which has occurred away from inductive style towards deductive analyses. Stronger grounding in *a priori* theory building has been largely responsible for this change but the development of facilities for large-scale computation has also helped this trend.

It is no exaggeration to state that electronic computers have made urban modelling possible. The testing of urban theories requires such an enormous amount of data concerning the most simple of hypotheses describing the workings of cities, that such experiment is only possible on large-scale computers. Thus the big number crunching exercises characteristic of urban models are now a reality. Furthermore, the hybrid nature of urban models in terms of their somewhat crude mathematical design often involves solution procedures which are approximate, which in short involve iteration. Such trial and error solution procedures represent the forte of the high-speed computer, thus enabling solutions to problems, which hitherto would probably never have been formulated and certainly never resolved, to be found. A further note on the development of urban theory is relevant here: urban models now represent the means for testing theory in a spatial context, and it appears that many of the newer theories of urban phenomena are model-based. No longer is it satisfactory simply to propose theories to be tested by others. More empirical support is required in formulating theory, and this has led to new developments in urban theory going forward under the guise of urban models. Thus urban modelling is not just a reflection of urban theory formulated elsewhere; it is now an essential part of theory in the fields of urban economics, geography and planning.

The rationale for developing models of the urban system is equally as strong in the fields of urban design and physical planning. The idea of designing a working model of the city with the notion that future plans for the city can be simulated and evaluated on the computer is an appealing and immensely exciting concept. The analogy between such computer application and the physical scientist's laboratory has been drawn many times (McLoughlin, 1969), and the use of such models in an experimental context seems to provide one of the foundation stones in the development of urban science. Yet despite the optimism of the planners concerned with the use of models in this way, the role of models in planning remains extremely crude and has never been systematically thought through. Such models appear to fit into any of the stages of the planning process – into planning analysis, the design of alternative plans, their evaluation and even their implementation – and thus the role of existing models can be tentatively ascribed as neutral. Certainly questions of the effect of models on design and optimisation in planning have hardly been broached although there are signs that designers are now coming to grips with the role of modelling in this field (Martin and March, 1972). The relationship between the use of models in hypothesis testing and in a predictive, possibly prescriptive context involves an inevitable source of conflict in the empirical development of this field. In some senses, every application of a model is unique and requires special adaptation to the problem in hand, and thus there is an element of hypothesis testing in every predictive model design. Such conflicts have been and continue to be a feature of urban model development. To trace the implications of these problems, however, it is first necessary to dig a little deeper into the origins of urban modelling, thus charting its recent history and setting the context for a more technical appreciation.

The Quantitative Revolution and the Systems Approach

The revolution in the social sciences and in related fields such as geography and the sciences of the built form which began in the late 1950s, was founded on the belief that progress in the development of knowledge could best be achieved by rigorous theory-building rather than by loose speculation. There was a genuine feeling among researchers that the benefits of the physical sciences would be bestowed upon the social sciences if more fundamental approaches could be developed. But this view was also coloured by the desire of social scientists to achieve a degree of respectability in the eyes of their fellow scientists and in the community at large. This change in approach which has pervaded almost every social science during the last two decades has been referred to in various ways, but two of the best-known clichés summing up these developments are termed the 'Quantitative Revolution' and the 'Systems Approach'.

The Quantitative Revolution is clearly demonstrated in the development of modern geography where concern for describing the nature of geographical space has involved the widespread use of mathematical and statistical description. The geometry of space and the statistical variation of spatial phenomena in locational terms have formed the basis for a new science of human geography, quite different in method and scope from the rather introverted regional geography which it has replaced. For example, the development of spatial abstractions such as idealised urban economic landscapes has led to the use of sophisticated mathematical analysis in the search for relevant theory. In economics, too, the descriptive tradition has been almost totally replaced during the last thirty years by analytical approaches which seek to explain, as well as describe the mechanisms governing the behaviour and structure of economic institutions and organisations.

The Systems Approach, on the other hand, appears to have been more formally adopted by disciplines whose content is less amenable to quantitative description. In response to the blurring of disciplinary boundaries in science and the realisation that many sciences use the same basic methodology, this approach was spurred on by the obvious relevance of *General System Theory* (Von Bertalanffy, 1971), and *Cybernetics* defined by Wiener (1948) as 'the science of control and communication in the animal and the machine', to almost every facet of human existence. Furthermore, the success of Operations Research as a common quantitative medium for analysis of a host of different 'human' problems was regarded by many as the arm of General System Theory which made the subject operational and usable in practice. The idea of systems being described in terms of structure and behaviour, in terms of input and output, and the notion of purposeful control of such systems in terms of negative and positive feedbacks, appeared to many social scientists an ideal description of their systems of interest and thus the approach has come to be used in more-or-less all of the social sciences.

The appeal and relevance of the system model can be formally traced through the work of Easton (1965) and Deutsch (1963) in political science, through Parsons (1952) to Buckley (1967) in sociology and less formally in a proliferation of works in economics, social psychology and geography. An excellent review article by McLoughlin and Webster (1970) lists pertinent literature from the social sciences and the reader is referred to this for further study. The Systems Approach however has been highly explicit in the fields of planning and design where the concept of control as well as system is of utmost importance. In physical planning, researchers and academics have been acutely conscious of the somewhat pragmatic nature of the subject and its lack of theory, and this has proved to be fertile ground upon which the Systems Approach has grown. Recently, this approach has been formally embodied in theoretical texts by McLoughlin (1969), Catanese and Steiss (1970) and Chadwick (1971) who have all brought their particular blend of Systems Theory to planning. Moreover, it is clear from these works that these authors regard urban modelling as one, if not the most important, medium through which the Systems Approach can be implemented in practice. In some senses, this is *a posteriori* reasoning for the origins of urban modelling go back further than the formal expression of planning as a Systems Approach.

The origins of urban modelling

The pioneer developments in urban modelling came almost exclusively from North America where two traditions were fused in response to the need for more systematic planning and better forecasting. Increasing car ownership during the 1940s and early 1950s led to the growing realisation that cities with their traditional physical form could simply not cope with the new mobility. Out of these problems came the first transportation studies in which planners and engineers sought to understand and solve congestion and by the late 1950s, the rudiments of the transportation planning process had been established. Part of this process involved forecasts of future trip generation and its spatial distribution and to meet these needs, trip generation was modelled using linear regression analysis, and distribution was modelled using the 'gravity model', so called because of its analogy with Newton's Law of Gravitation. These modelling techniques were widely used and in the absence of evidence to the contrary, these techniques appeared successful in that they were fairly manageable and simple to operate. Yet the transportation studies neglected many important questions concerning land use and it was inevitable that transport engineers should attempt to take such questions into account by extending their ambit to encompass land-use forecasting. The interrelationship between traffic and land use was a subject of much practical and academic debate during these years and the pioneering work of Mitchell and Rapkin (1954) in their book *Urban Traffic: A Function of Land Use* did much to convince engineers and planners of the need for integrated land-use and transportation planning.

The immediate success in operational and academic terms of transportation planning and modelling naturally led those concerned to begin to think about the possibility of building land-use models, and by 1960 several such models were under construction. But another tradition apart from transport planning had an effect upon such developments and this concerned research activity in urban and location economics. Two important research projects involving theoretical models of urban structure were nearing completion at this time. The intra-urban location model designed by Wingo (1961), and the similar but slightly more theoretically oriented economic model proposed by Alonso (1960) established an economic theory for urban systems, comparable to existing theories of economic location in regional systems. These models together with other more empirically based research in urban economics being initiated at the RAND Corporation (Kain, 1962) had a profound influence on the development of the first generation of urban models in the early 1960s, and this work is so important that it warrants further explanation.

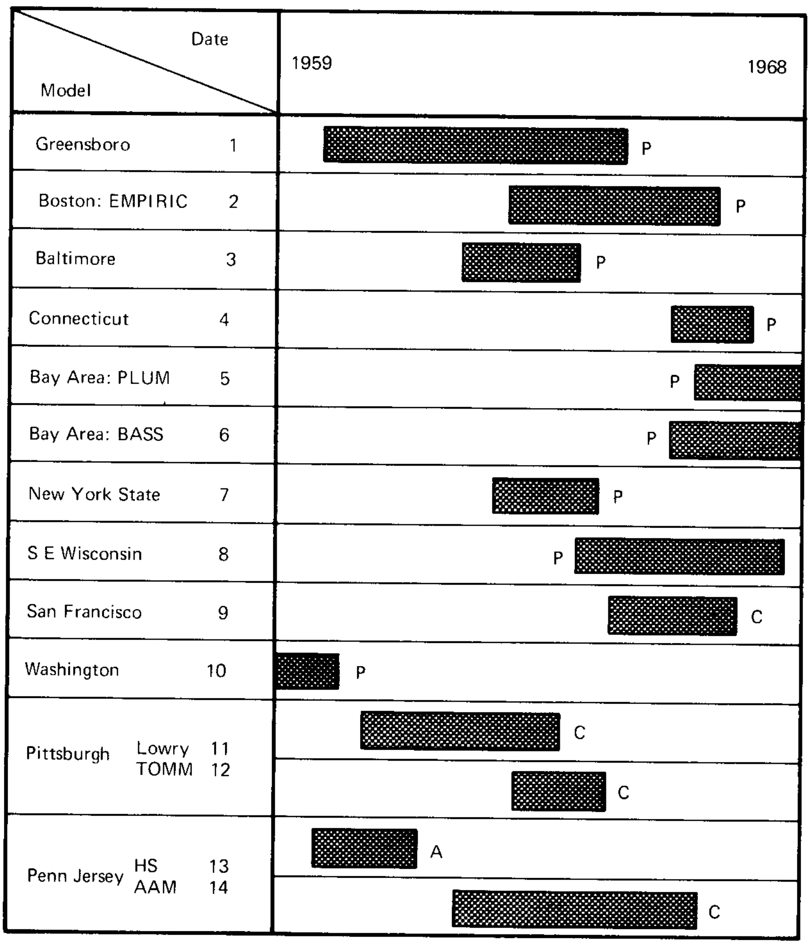
The synthesis achieved by Alonso and Wingo at this time grew out of certain simple and long-established ideas concerning location and the price of space around a market centre due to Von Thunen (Hall, 1966). In 1826, Von Thunen suggested that around a market centre, the rent paid for agricultural land plus the cost of transporting agricultural produce from the land to the market would equal a constant value. At the margin of development, rent would be zero and the total cost incurred to the producer would be equal to the transport cost to the market. From this statement, it is not hard to deduce that rent would decline with distance from the market centre, and subsequent empirical evidence bore out this simple result. Von Thunen's work was largely neglected in the subsequent years although it became apparent that not only rents but other activities such as population density and trip-making also declined with distance from the centre (Clark, 1951). Wingo's achievement was to design a model based on Von Thunen's work but integrating detailed transport costs and explaining population density, and Alonso took this work a stage further by setting the whole model within the micro-economic theory of consumer behaviour based on utility-maximisation. A major restriction of these analyses concerned the fact that only one centre could be treated – the monocentric assumption; but it was clear that the trip-distribution model which treated many centres was consistent with these theoretical models and thus the way lay open for ambitious land-use modelling integrating theoretical elegance with operational feasibility.

A short history of first generation urban modelling

The first generation urban models were designed and implemented in North America mainly during the years 1959–68, years which coincided with the launching of large-scale land-use–transportation studies in major metropolitan areas. There are some excellent reviews of model construction during this period and in particular the reader is referred to the work of Lowry (1968), Harris (1968), Kilbridge, O'Block and Teplitz (1969), Brown, Ginn, James, Kain and Straszheim (1972) and Lee (1973) who have all provided useful summaries of the modelling experience. Boyce, Day and McDonald (1970) in a fine review of metropolitan plan-making also present pertinent material on the planning environment within which these modelling projects were initiated; although this section will draw on these works, the discussion is in no way a substitute for reference to these reviews but is an interpretation of the most important facets of the North American modelling experience.

One of the striking features of urban modelling during these years was the almost exclusive development of models in practical planning situations. Apart from the work of Chapin and his colleagues in North Carolina (Chapin, 1965), most of the fundamental research into urban modelling was carried out under the auspices of metropolitan planning agencies or consultants, a situation probably due in part to the practical need for better forecasting, the continuing tradition of transportation modelling and the availability of federal funds. Yet an extensive variety of approaches was utilised involving a diverse selection of techniques ranging from linear regression and gravity modelling to mathematical programming. Emphasis on theory ranged from the pragmatic to the pure, and the approach to modelling from the most partial to the most general. The models can best be grouped according to the techniques used. Conventional and well-established linear statistical techniques were used as a basis for several models, in particular the Greensborough model (Chapin and Weiss, 1962), the EMPIRIC model of the Boston Region (Hill, 1965) and the Baltimore and Connecticut models (Lakshmanan, 1964, 1968). Non-linear models such as the Delaware Valley (Penn–Jersey) Activities Allocation model (Seidman, 1969) were constructed in a similar fashion and most of these attempts reflected a somewhat inductive approach to modelling with little *a priori* theory. In contrast, the many models built around the gravity model suggested a more deductive approach in which specific mechanisms at work in the urban system were simulated. The Pittsburgh model (Lowry, 1964) and its successors, the Pittsburgh Time-Oriented Metropolitan Model (TOMM) designed by Crecine (1964) and the Bay Area Projective Land Use Model (PLUM) designed by Goldner (1968) as well as the Upper New York State model (Lathrop and Hamburg, 1965) are good examples of the gravity modelling approach, an approach which appears in retrospect to have produced the most successful urban models during this time.

Models based on mathematical programming such as the residential-location model originally proposed for Penn-Jersey by Herbert and Stevens (1960) and subsequently developed by Harris (1972) at the University of Pennsylvania, and the South East Wisconsin Land Use



REFERENCES TO MODELS:

1 : Chapin and Weiss, 1962,
2 : Hill, 1965,
3 : Lakshmanan, 1964,
4 : Lakshmanan, 1968,
5 : Goldner, 1968,
6 : Wendt *et al.*, 1968,
7 : Lathrop and Hamburg, 1965,
8 : Schlager, 1965, 1966,
9 : Robinson *et al.*, 1965,
10 : Hansen, 1959,
11 : Lowry, 1964,
12 : Crecine, 1964,
13 : Herbert and Stevens, 1960,
14 : Seidman, 1969.

A: abandoned; C: calibrated; P: used in prediction.

Fig. 1.1. Urban modelling projects in North America during the 1960s.

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Plan Design models built by Schlager (1965, 1966) show how optimisation techniques can be used in urban modelling although there has only been limited success with these techniques. More hybrid modelling schemes such as the Bay Area Simulation Study (BASS) initiated by Wendt *et al.* (1968), and the San Francisco Housing Market Model (Robinson, Wolfe, and Barringer, 1965) which attempt to link several different techniques were also tried although a large measure of arbitrariness is often a feature of such schemes. Figure 1.1 presents a chart of model developments in North America from the years 1959–68, and from this chart, it is evident that the peak in modelling activity occurred in the early- and mid-1960s. Although only a sample of models developed during these years is presented on the chart, most of the important applications described in easily available publications are included.

Although a great deal was learnt from the first generation of urban modelling, the experience was somewhat unprecedented in that several fundamental factors affecting the whole process of modelling were only discovered after the model construction had begun. Reactions to the relative failure of these early models differ quite widely: for example, Lee (1973) considers the experience to have been a salutary warning of the dangers of technocracy whereas Ingram, Kain and Ginn (1972) regard these early attempts as vindicating the view that modelling is a large complex affair which requires far more resources than were then and are now available. The first major problem confronted by most of the early models involved questions of size. Many of the models were so ambitious in terms of their scale, the data required and computer time and capacity needed, that real time and money ran out and the models were then abandoned or drastically pruned. Classic examples of such failures were the San Francisco Housing Market Model and the original Herbert–Stevens model for Penn-Jersey. At the same time in North America, disillusionment with technology began to grow as planners and politicians began to realise that long-term planning of transportation and land use had little or nothing to do with more immediate problems of poverty and inequality. One by one the funds available for such long-term projects were diverted to more critical and pressing problems. Optimism among model-builders and planners turned to pessimism and bitterness and after the mid-1960s 'sharp criticism forced the movement to go underground' (Lee, 1973).

It is easy to blame excessive ambition, lack of time and money, and changing priorities for the failures in first generation urban modelling, but the quality and limitations of the models also had a great deal to do with the situation. At the beginning of the decade, urban modelling seemed to present a means for cutting through and tackling the complexity of the modern metropolis. Lee (1973) sums it up nicely in the following