

NCGIA

**National Center for
Geographic Information
and Analysis**

**Locational Models,
Geographic Information,
and Planning Support Systems**

by
Britton Harris

Department of City and Regional Planning
University of Pennsylvania
Philadelphia, PA 19104-6311
And

Michael Batty

NCGIA, Department of Geography
State University of New York at Buffalo
Buffalo, NY 14261

**Technical Paper 92-1
January 1992**

ABSTRACT

In the 1990s, one of the dominant modes of computation will be in graphics, picture and image processing. All applied fields will be affected although none more so than those areas such as spatial planning and decision-making whose modes of analysis and communication are based on maps. Already, Geographic Information Systems (GIS) are becoming widespread in management and planning, and their focus and form is beginning to affect the organization and operation of policy-making. In this paper, we address the problems and potential of such systems, particularly in relation to the analytical, predictive and prescriptive basis on which such planning processes are founded. Current GIS are not rooted in the sorts of function and activities which drive the planning process and here we will identify the difficulties and possibilities for developing more appropriate GIS which are sensitive to the sorts of simulation, optimization and design activities on which spatial planning is based. To this end, we will describe the development of Planning Support Systems (PSS) in which a wide array of data, information, and knowledge might be structured, and within which GIS development must take place. We will identify the sorts of urban system and locational models which characterize planning and whose data demands might be accommodated using GIS. Our critique of GIS though is positive and constructive in that we are concerned to embed GIS into planning processes in their most relevant form. By way of conclusion, we will identify a series of requirements which PSS must meet.

ACKNOWLEDGEMENT

This paper represents work that is related to research being carried out at the National Center for Geographic Information and Analysis, supported by a grant from the National Science Foundation (SES-88-10917). The Government has certain rights in this material. Support by NSF is gratefully acknowledged. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

1. INTRODUCTION:

DATA, INFORMATION, KNOWLEDGE, AND INTELLIGENCE

In this paper we attempt to bring together several different views of data and information, with the aim in mind of sorting out the difference amongst their uses for various purposes of planning. This will of course involve us in a discussion of existing and proposed systems of data management and display, together with issues about its acquisition and manipulation. We will focus especially on an examination of the possibilities of using Geographic Information Systems (GIS) for statistical analysis, research, management, and planning. Within this context we will place special emphasis on the use of information in urban and regional planning, and by an extension of the ideas lying behind management information systems and decision support systems, we will examine the possible nature of a Planning Support System (PSS) in relation to a GIS.

Our development is informed by a paradigm of information and knowledge which suggests a number of different levels in a hierarchy. Raw data is recognized upon its acquisition from one of many different sources in one of many different ways through events in the real world and the world of the mind. Data is converted to information by various forms of filtering and processing which give it some form and coherence at a rather elementary level. Scientific processes of generalization and the investigation of cause and effect convert information into knowledge by imposing and testing a structure which is usually not inherent in the original data or the processed information. Knowledge may be converted into intelligence whenever it is applied to new ideas, suppositions, and information in an organized effort to interpret new information or to take a purposeful view of the future (Penzias, 1989).

In this light, it will be helpful at the outset to try to set forth a synopsis of our views, in a way which will clarify and lead the following discussion. We face the difficulty that we will be discussing the contributions of several different disciplines and professions, but we see this as a necessary counterpart to the discussion of systems which are intended to have a certain generality of application for many different purposes. Indeed, a part of our intent is to indicate where the search for general purpose implements may break down precisely because of the different requirements of different disciplines and professions in using data and information. Such a breakdown, if correctly identified, can be regarded as a caution against trying to impose the views of one discipline upon another, or alternatively as a challenge which points us in the direction of improved general-purpose implements. We take each of these positions in different contexts.

In a nutshell, our view is that GIS, properly considered, are defined in a way which provides very important types of support and control to many other systems and many activities, but that they are sufficiently limited by their intrinsic nature to fail if they are used as the exclusive tools of analysis and planning. They support the organization of information in certain ways, but not necessarily in ways which then support every type of production of knowledge or intelligence. A profession like planning may unduly limit itself if it accepts the idea that GIS can discharge all or most planning tasks. Even geographic analysis may find itself limited in scope if it relies solely on GIS - although they share the disciplinary background of Geography. Conversely, the designers of GIS should avoid the presumption that their systems are a universal panacea for problems of spatial data management, analysis, and planning. Not only is this presumption unfriendly to the neighboring disciplines in which GIS are used, but any ultimate failure of GIS to solve all problems could react against their acceptance for problems in which they perform well. It must be said that to a large extent this potential difficulty arises out of the attitudes of commercial vendors of GIS software more often than out of those disciplines of Geography and Computer Science. All of these problems flow quite naturally out of the basic orientation and the corresponding strengths of GIS. The best of these systems maintain an attitude of strict responsibility toward the accurate maintenance and manipulation of geographic information, in digital and computable forms. Systems which do this well may be compromised for other uses by the intense demand for heavy computation which this approach imposes. The cumbersome nature of GIS in approaching other computational tasks can give GIS a bad name. Yet an effort to simplify the treatment of geography as the basis for an operational system which supports another approach can weaken the treatment of geographical and topological relations. If this is done under the name of GIS, it too engenders disrepute, limiting its impact and generating disillusion with computation as an approach to planning.

This issue can be stated more exactly. The greatest strength of GIS is in creating new information and combining diverse sources of geographic data (both purely geographic and comprised of geographic attributes) through the process of overlays; this requires large geographic files and extensive processing. The other processes which use geographic data generally work with fixed definitions of area systems and devote their computational efforts to statistical computations, managerial use of large data files, and simulation. GIS specializes in disaggregation, while most other processes emphasize aggregation. The processes which transform information in statistics and simulation are completely different from the processes which transform geographic data on maps or their computer representation. For GIS, geographic details are in the foreground, while for other processes the geography should be in the background, but correctly represented and well-controlled. Both approaches may meet again when results are presented and maps need to be drawn.

These bald introductory remarks run ahead of our argument. We will therefore begin to develop our position from somewhat different points of view. First we will sketch out the kind of computer environment or landscape in which GIS is being developed and

in which contemporary planning must now operate. To this end, we will describe the evolution of the current generation of GIS and related systems with a view to explaining their role in planning, while at the same time indicating the types of planning process in which such systems might be useful. We will then outline the types of system theory and models, formal and informal, which planners use to help in articulating and analyzing problems, forecasting outcomes, and designing solutions. These models and the substantive theory from which they are derived generate strong requirements for data which is informative in terms of the characteristics of the systems they address, and in this context, we have already anticipated that GIS used in relation to such models are fairly limited in their support for planning.

We will then deal with the problems posed by the planning process itself, the ways in which planning is based on goals and objectives which are optimized (at least in part) through designs and the types of information required to serve and advance such processes. If current GIS fall short of the requirements of urban system models, they barely consider those requirements posed by the planning process. The sorts of data required in representing goals and objectives, costs and benefits, and the ways in which such data are transformed by the planning process hardly exist in GIS, and thus an important conclusion from our argument will involve requirements for both information systems and the wider planning support system in which GIS can be embedded. Finally we will define a number of key requirements for the development of planning support systems and we will conclude by suggesting how such systems might be designed.

II. THE NEW LANDSCAPE OF INFORMATION

In reviewing the computerization of society over the last 40 years, there is a strong tendency to emphasize the development of hardware and software and to neglect the increasing volume of raw and processed data which society has at its disposal. Computers have obviously brought in their wake a dramatic increase in data although we know little about its general form and impact on every-day life. It is clearly easier to chart the development of hardware along the path of miniaturization and software along the path from numerical coding to visual abstraction than it is to measure and classify the way data on every aspect of society has increased and diversified. Yet even casual reflection suggests that this growth has been as haphazard as it has been dramatic, and that its impact is increasingly opaque.

A general approach to handling data however is ever more urgent as we are about to cross a threshold in which computers and data banks which access and store data are connecting up through the burgeoning networks of communication. Yet even the impacts of the most general and pervasive of such sources of data such as those found, for example, in personal finance and credit are difficult to gauge, and there is little knowledge concerning the inconsistencies, problems of coordination, the accuracy and bias of the data that is being assembled. The landscape of information which this data supports is one which is barely charted, rapidly changing and undoubtedly uneven in every form. From the viewpoint of science, it is easy to sense but hard to measure how data is changing the way we are think, theorize and generate new ideas. Rapid changes in the intellectual landscape are difficult to evaluate and only when the dust settles, will it become clear whether the many new ideas which the computer revolution is spawning, are truly new. At present it is hard to know when, if ever, this era of rapid change will stabilize. Moreover, a central problem which we will continue to face is the mismatch between the types of data which are being collected and processed and the data which we require for particular intellectual tasks. One aim of this paper is to explore this dilemma with respect to the various information systems and their data which are currently being developed for spatial decision-making in general and urban and regional planning in particular.

In terms of planning, this new landscape is characterized by the development of information systems, the best specified of which are those which deal with recording, processing, and communicating spatial data. These systems are referred to generically as geographic information systems (GIS) although this term covers a wide variety of software systems dealing with data at different spatial scales, over different time spans and with different conceptions of use in mind. At the outset we must distinguish such generic systems from actual systems which are being developed and applied to planning, and in this paper, we will concentrate on the development of generic systems appropriate to the various activities and functions of planning. GIS deal with two general categories of data. First there is data which characterizes the intrinsic structure of the spatial systems in question and this relates to the geometric and topological structure of space. Such data is represented in two-dimensional digital form, sometimes three. Related to this are attribute data of two types: data describing the physical features of geographic space, and socio-economic data pertaining to various elements of space and their aggregation. In fact, most systems developed to date are strongly oriented towards the representation of space using digital data and many of their system functions involve the manipulation of space. The analysis of socio-economic attributes is based on spatial manipulations, and such analysis is often simplistic being in mainly concerned with the display of data. The origins of GIS in computer mapping are revealed by these characteristics, and the use of such systems for mapping is still one of their main tasks. Here we will explore the problems posed by using such systems in planning where the functions required are somewhat different from those which characterize the current generation of GIS.

It is tempting to compare the growth of GIS with the development of word processing a decade or so ago, for undoubtedly the 1990s will be a period when graphics or picture processing will become widespread. But GIS are somewhat more specialized in focus despite the fact that they are being applied to a wide variety of professional tasks. At one extreme, these systems merge into

those developed for computer-aided design and drafting especially at the finest spatial scales. At larger scales, such systems relate to remote sensing. Across many scales, various types of image processing are being developed to complement their use. Nevertheless, the dramatic growth in the use of such systems is still surprising in the face of their simplistic nature. In fact, it is likely that because such functions are so elemental in their emphasis on the representation of maps that they enjoy widespread popularity, but this poses major problems for application areas such as urban planning where such systems are required to interface with complex models set in a sophisticated problem-solving, design, and decision-making process. Parker (quoted in Forrest, 1990) calls GIS "...a chameleon technology..." and he goes on to suggest that its power relates to the fact the technology is so adaptable. But this generality is being secured at the expense of tailoring such systems to specific functions and it rests on the questionable assumption that all practical contexts which make use of these techniques have similar requirements with respect to spatial data.

There is another issue here and this involves the difference between data and information. Martin Shubik (1979) a decade or more ago cogently remarked "...ours is a data-rich but information-poor society." In fact, it is the functions to which information systems are put which transform data into information, and thus the extent to which such systems inform relates to the functions which they enable. GIS are based on elaborate functionality which relates to their manipulation of spatial geometry and topology for many of their processing operations involve filtering, generalizing, overlaying and aggregating the elemental points, lines, and areas which represent space. This in itself is informative with respect to how space can be structured but it is rarely backed up by any substantive model of the system of interest or the problem in question. When socio-economic attributes are added to such systems, the physical geometry of spatial representation drives the way such attributes are processed and displayed. It could thus be argued that from the point of view of the design of new systems which resolve or alleviate current problems, such information systems are of less use than are those systems in which the nature of the problem and the way it is to be addressed form the rationale for spatial representation.

Harris (1991a) argues that information systems for planning must be constructed with at least three interrelated bodies of theory in mind: the theory of computing, social and functional theories of the systems being planned, and the theory of planning. To this we should add a fourth based on the theory of spatial representation or description. In general we will suggest that these four approaches to the spatial world determine the framework which we are calling planning support systems (PSS). We will argue in this paper that existing GIS and related information systems fall far short of the requirements for such planning support (Harris, 1989).

Planning support systems are somewhat broader than those decision support systems which exist in management and they are variously referred to as spatial decision support systems (Densham, 1991), creativity support systems (Manheim, 1986) and suchlike. Most contemporary GIS have been developed with theories of spatial representation and of computing or processing in mind but there are few which have sought to develop their functionality with substantive systems and their design or planning in mind. In this sense then, the current generation of GIS are likely to be unsuited to most planning tasks. This is not a criticism of GIS per se but simply a statement of their limitations. Current systems represent only the beginnings of an emergent landscape of information in which the planning of post-industrial cities will be determined. One goal of this paper is to develop a critique of present systems and to suggest how they might be improved, adapted and rebuilt to the tasks and requirements of contemporary planning. We will begin with a description of how GIS has evolved.

III. THE EVOLUTION OF GEOGRAPHIC INFORMATION SYSTEMS

In the 1950s and 1960s, the paradigm which most influenced the development of urban planning was based on general systems theory. Cities and regions were considered to be complex systems whose structure could be understood in terms of hierarchies of subsystems, spatial and otherwise, embedded within dynamic frameworks whose equilibrium properties were assumed to be quite tractable. Planning such systems was seen to be one of optimizing some general systems property such as utility or welfare, and the ideal type of system model embodied such optimization in terms of system behavior (Harris, 1959). In cases where such optimization was clearly not systemwide, planning was seen as akin to introducing some control mechanism into the system of interest. This characterization was clearly an 'ideal type' in that nowhere did any real city or regional system closely approximate this type of functioning. In fact, this view of system models merely pointed the direction towards optimization in that although models of the system could be developed in terms of optimal and non-optimal behavior, such models were seen as simply informing the wider and more significant process of planning, which in turn existed as part of a still wider political reality.

In this context then, planning embraced system models and these models were, in turn, regarded as embracing the information systems useful in making them operational. The process of relating information, model and planning systems however was structured in a sequential process beginning with description and understanding, continuing through the survey and information systems design, in turn being enhanced through system modeling, and then moving into a design phase in which alternative plans were generated and evaluated often through predictive and prescriptive system models. The two phase nature of this process was and continues to be referred to variously as 'analysis-synthesis', 'problem definition-solution', 'simulation-optimization' and so on (Simon, 1969). When this process was explored and applied in the context of land use-transportation planning some three or more decades ago, it was predicated on the basis of a rational technocracy in which the requisite data for planning could be obtained, system models

producing informed understanding based on this data developed, and best plans selected unambiguously from a range of relevant alternatives generated (Batty, 1979).

The ensuing reality was somewhat different. The initial enthusiasm for computerized modeling and planning was quickly tempered by the difficulties of collecting the relevant data, by the sheer extensiveness of the task in terms of data representation, and by the difficulty of developing appropriate system models (Brewer, 1973; Lee, 1973). Problems pertaining to the selection of the best plan also plagued the process but it was the shift in the perspectives of the planners and decision-makers which most undermined these developments. The shift from planning as a process of optimizing spatial allocation in terms of limited efficiency and equity to one based on much more general, broader-based issues of equity, as well as the increase in uncertainty posed by global crises of energy and economy, served to increase skepticism that the use of this technology represented the way forward to better planning. During the 1970s when this style of planning became less fashionable in favor of a more pragmatic response, the intellectual high ground in planning came to be dominated not by planning theory but by questions of ideology and social theory. In fact, during the last 20 years, planning has become ever more pragmatic as it has attempted to respond to and embrace new fads and fashions (Batty, 1979).

It is behind this cloak of pragmatism that geographic information systems have developed. The computer revolution, which began to make itself widely felt in a personal context with the development of the microcomputer from the mid-1970s, was clearly necessary for advances in graphics which enabled computer mapping to become routine. Once such mapping became possible on microcomputers, then demand for such systems became widespread. In parallel, the increase in spatial data which was spurred on by the existence of a technology to support it, and the ever-increasing bureaucratic needs of a complex society created an enormous demand for appropriate information systems. In particular, the storage and processing of local administrative data and of population census data, and the increasing availability of digital data from agencies dealing with map production such as the USGS and from the Bureau of the Census, were instrumental in the development of systems dedicated to the manipulation and display of such data.

As planning became more pragmatic and concerned with individual systems, the demand for data systems relating to facility location and scheduling such as emergency services, to resource management and conservation, to property and tax registers and so on increased the need for geographic information systems (Densham and Rushton, 1988). In short, such systems developed in response to all these trends and needs. GIS were developed in as simple a form as possible so that they could be adapted to a wide variety of basic tasks from computer mapping to simple data classification, across a range of scales and for diverse systems types. For example, Forrest (1990) lists over 60 distinct systems and problem areas to which such GIS might be applied with examples as diverse as navigation to political redistricting and as wide as hazardous waste management to wildlife protection. Furthermore such systems acquired more and more the characteristics of toolkits in that their design embodied enough flexibility to accommodate a wide range of problem types (Dangermond, 1990)

Given the lack of any strong intellectual framework other than cartography within which GIS has been developed, and given the absence of strong institutional constraints, it is easy to understand how developers and vendors of GIS have continually broadened the appeal of their product as a simple general purpose instrument. This clearly runs counter to the development of task specific applications, although the existence of a narrow but varied set of applications has meant that the developers have standardized upon ways of inputting and outputting data as well as upon agreed conventions for relational data representation and display. Thus the key issues in the development of GIS have not been on the extension of such systems to task specific functions but upon improving the representation of spatial data. For example, there has been wide discussion of cartographic analysis within such systems concerning the development of optimal methods and algorithms for spatial search. The representation of spatial data in raster or vector form has conditioned the development of different systems although more recently, methods for moving between the two forms are being embodied in most systems. The question of scale of representation however has not been the subject of much analysis to date although there is significant research in progress (Buttenfield and McMaster, 1991).

It is often assumed that a GIS should be equally able to represent data at sitespecific scales where cadastral data forms the base, to regional scales and above where thematic mapping is of the essence. At even higher scales, map projections are essential components of GIS, and in many such contexts, the origin of the data from remotely positioned sensors guides their construction and use. Most systems have not been developed with time series data in mind; in fact, this same bias exists in the development of system models in the strategic planning process. The sorts of GIS which we are alluding to here have some difficulty in being adapted to routine problems where data is being continually updated and where real time access or at least frequent access is required. In these domains, for example in land use zoning control, in emergency service response, in traffic management and so on, special purpose information systems combining the functionality requisite for control of the system in question have been designed. Finally although state-of-the-art GIS are being evolved to embrace raster and vector, network and area representations, as well as sophisticated and general ways of importing and exporting raw and processed spatial data, most systems are oriented towards static problems where the emphasis is upon the spatial display and mapping of standardized data such as that available from population censuses.

During the last decade, GIS have come of age in that there now exist upwards of 100 such systems which enable raster and vector geometries to be efficiently handled, thematic and cadastral mapping to be easily applied, and physical operations such as

overlay and buffering to be effected on spatial data. Recently, the emphasis has been upon developing stronger relationships to other widely available software through input and output standardization, and there is now some evidence that some systems are beginning to be extended to embrace more specific functionalities such as those required in land use planning (Batty, 1991). For example, ARC-INFO is being extended to contain explicit spatial interaction modeling while systems such as GIS Plus and TRANSCAD have been designed from scratch with transportation planning in mind. There is both a convergence and divergence occurring. A standardized set of basic GIS operations on digital data together with basic display facilities now characterize all state-of-the-art GIS while different systems are clearly being developed for specific tasks with regard to the type of planning, problem-solving, design or control associated with the activity in question. At the finest site-specific scales where precise measurements are needed for the construction of physical facilities GIS which are more like computer-aided design and drafting systems such as AUTOCAD are developing, while at the global level systems such as ERDAS designed to work with remotely sensed data have been developed.

The functionality of the present generation of GIS is thus based on comparatively low level processing operations which pertain to spatial geometry. As yet there are few high level functions relating to particular system models and planning tasks embodied in such technologies although these are being added to several systems at present (Birkin et al., 1990). Where GIS are used in planning, their use in relation to particular stages of the planning process is informal in that they are seen as being useful and efficient storage and display media for spatial data (Huxhold, 1991). The range of spatial analytic functions useful for preliminary analysis of data is also fairly limited in such systems, these having to be added through fairly tortuous yet ingenious programming using system macros (Ding and Fotheringham, 1992). When it comes to using such systems as a basis for spatial modeling, for optimization and for design, their use is informal at best, depending upon the skills of the user in forging a link between the GIS in question and other standardized as well as customized software (Densham, 1991).

We can thus conclude that with respect to the planning process and the use of appropriate system models for description, analysis, prediction and prescription, the current generation of GIS hardly approach the kinds of functions which planning requires. The kind of planning support system which generates useful information requires system models, data relating to the analytical and design stages of the process based on goals, objectives, costs, benefits and so on, as well as information generated through the process itself as issues become better defined and as the need for new data is generated through learning about the nature of the problem. For GIS to be truly informative in this context, they must be consistent and strongly linked to problem definition and the system models used to inform the overall planning process. To this end, we will now describe some of the functions of planning support which should ideally be embodied in relevant information systems before we continue with identifying the data and information requirements of relevant locational models.

IV. THE FUNCTIONS OF PLANNING SUPPORT

Planning support systems form a framework in which three sets of ideas and functions are combined. Clearly the tasks which comprise the planning process however they might be defined, are part of the structure to be supported by various models or conceptions of the system of interest and its problems which planning aims to resolve. This process generates its own information which involves the problem and the way it is likely to be alleviated, solved or resolved. A second variety of information is associated with the system models which are employed to inform the planning process through analysis, prediction and prescription. Such models are informative insofar as they are able to capture the essential workings of the system in question, information being generated through their application to the problem in hand. A third basis for information involves the systems which are used to transform basic data into information which in turn provides the driving force for modeling and design. The process from data systems through modelling to planning however is not one way for information which is produced and generated during the planning process alters the process itself and thus must be stored, retrieved and communicated back to the data systems and models responsible for their generation in the first place. In this sense then, information is continually created, destroyed and transformed as the process proceeds and as the planner cycles purposively and intelligently through its various stages, generating the knowledge necessary for informative planning (Batty, 1990).

As we have been at pains to point out, data is not information, and data systems are but the first step in a convoluted chain of transformations which govern the way basic problems are defined and described, goals and objectives for their solution specified, plans and policies generated and evaluated, and the best set of such plans ultimately chosen and implemented. Moreover, the problems which are identified and which drive the planning process can pertain to many problem domains, each with different conceptual and operational models in mind and each giving rise to a multifarious data requirements. Even in the comparatively narrow domain of urban and regional planning, the types of problems defined can vary widely and there is no basic consensus about the best or most relevant theories and models which define the system of interest. Consequently, data requirements for seemingly similar planning problems can differ radically. Moreover, the plans and policies involved can differ to the same degree. Based on the view that there is never likely to be a completely consistent and general theory or model which encapsulates all the elements of the problem in question, practical planning is likely to embody many styles, many models and their theories, and consequently many differing, sometimes contradictory, sometimes complementary data systems. In short, the notion that there will be a plurality of information systems, models and planning processes relevant to any single problem is the reality we have to work with (Couclelis, 1991).

Nor is information timeless in its definition and use. The problem in question which motivates the need for planning will be based on some perceived evolution of the system in question, on some temporal divergence between the real and the ideal. Theories and models which are based on substantive ideas concerning the functioning of socio-economic systems are usually dynamic in some sense and pertain to the process by which the past has evolved to the present. Data informing this evolution is likely to be important. In contrast, planning is about creating ideas and plans which will inform the future. This type of data is speculative and ill-defined yet it exists throughout the planning process, being created through the use of system models in prediction and prescription. Information systems as they have evolved in the spatial domain however generally contain data which pertains to the present. Such data defines the instant in time at which the problem is conceptualized and planning begins and in this sense, is what Harris (1991b) has called the "...knife edge between that past and the events still to come". Most GIS focus here and while being highly sophisticated in terms of spatial data, are somewhat underdeveloped in terms of temporal data. This is a bias which emerges from a lack of concern for the wider theoretical and substantive context of the problems and systems in question to which such GIS are being applied. Moreover, appropriate information systems for planning are by no means exclusively spatial in focus. The data required in planning is always a mix of the spatial, aspatial and nonspatial, a blend of the qualitative and the quantitative, covering a wide range of physical, social and economic attributes many of which are non-comparable with one other. Moreover as we have implied, the planning process generates its own data and information about the future which has significant a status as data pertaining to the past and the present. GIS are not well-adapted to such conceptions, thus implying that these systems can at best only provide useful information with respect to somewhat narrow aspects of typical planning problems.

The multifarious functions of a planning support system, therefore, define the data which is required, and the way these functions are used in the process determine the channels whereby this data is transformed into information. We can interpret information as forming the glue which binds the individual stages of the planning process together. This process can thus be considered to be based upon flows of information which define the purpose of the planning task, and the plan can be seen as the ultimate form of information in its transition from data concerning the problem to that concerning the solution (Le Clercq, 1990). Data, system models and related formal and informal analysis, as well as procedures which enable the design of solutions to planning problems through plans thus establish the need for information systems which deal not simply with past and present data but with data which emerges from the planning process itself; this data may be transformations of the original data, collections and organizations of new data whose demand is a result of the process, data which pertains to the future of the systems of interest through prediction and prescription as well as data which is generated by learning about the problem and by adapting the process to the problem in hand. GIS rarely meet the challenges posed by such diverse requirements of planning although they still remain a critical part of the planning process and the development of system models which are based on their data.

V. LOCATIONAL MODELS AS A BASIS FOR PLANNING SUPPORT

The typical system models which support the urban planning process have been derived from a wide range of disciplinary and methodological perspectives. All disciplines have an impact on the study of human systems but here we will mainly focus on those which treat behavior in terms of social and economic characteristics, consistent with the goals of spatial planning although we will allude to system models which emphasize the relation between human and physical in terms of ecology and energy. In our treatment of such systems, the concepts of a well-developed system structure which can be organized in terms of hierarchies and networks of subsystems together with system behavior which is equilibrating in some sense will be central. The dynamic evolution of such systems is usually studied in terms of a balance between various forces, in economics demand and supply, in ecology predator and prey and so on, and here we will deal with models in which such balance is assumed to be the usual condition of the system or at least the state which such systems are evolving towards (Simon, 1969).

Location models useful to urban and regional planning emerge from the two traditions of economics, macro and micro, although the richest of such models are those based on human spatial behavior at the micro level; this is where we will begin. The notion of cities as a system of markets in which land is the commodity and rent indicative of the price mechanism is well established in location theory, and the richest such models attempt to simulate the way in which such a spatial equilibrium emerges (Anas, 1987). Congestion in the transport systems and wages in the labor market can also be regarded as equilibrating forces. In these models, which now form the basis of most housing market and travel demand models, the demand for land and housing by consumers and producers and its supply by developers is resolved through the price mechanism in which incomes and transportation costs are related to utilities and profits. In this sense, most urban economic models follow the traditions of microeconomics in which consumers maximize utility and producers maximize profit. Thus in a very special sense, these models might be regarded as optimizing and the competitive equilibrium which is ultimately established can be usually be interpreted in terms of welfare or consumer surplus. It is assumed that planning enters these systems through mechanisms which resolve various types of market failure in which some collective welfare cannot be optimized by the market itself. However, it is fair to say that in the use of these types of model in planning, specific welfare maximization through planning is not normally embedded within the formal mechanism of the models themselves. In short, these models are not usually taken as the formal basis for the optimization and thus these models like most in planning are used to describe, analyze, predict, and evaluate, but not to prescribe.

A well-developed body of theory has been developed in these domains over the last 30 years. Urban economics and travel demand modeling represent the most completely worked out of these domains although many operational urban models pay some lip service to conceptions of the market and market equilibria. In housing markets, the models developed by Wingo, Alonso, Muth, Mills to Beckmann (1969) amongst many attempt to explain residential location in terms of utility maximizing, and the best developed operational developments can be seen in the work of Anas (1982). Models of retail location too have been well-developed in terms of their embedding into dynamic frameworks in which demand and supply are balanced and several operational versions of such models now exist to inform decision-makers as to the most appropriate locations for new and expanded retail centers (Harris and Wilson, 1978; Fotheringham and O'Kelly, 1989). In modeling travel demand, the discrete choice approach in which travelers optimize their utility but randomly over a range of possible values has been well-developed since the mid-1970s (Ben Akiva and Lerman, 1985) and there are several attempts to link such models to those which were derived more pragmatically as gravitational analogues in a statistical optimizing framework (Wilson, et al., 1981). Recently there has been considerable interest in the development of equilibrium travel demand-supply capacity models in which balance can be achieved consistently over trip generation and distribution, modal choice and route assignment. Throughout these areas, there have also been attempts to synthesize such models through various optimization schemes which can be regarded as close to one another, for example, through utility, welfare, entropy, likelihood, and related schemes of maximization (Anas, 1983).

All these models generate data demands which can be quite formidable in terms of data collection. Spatial interaction in the form of flows between locations relevant to the housing market, the workplace, the retail sector and other related services are crucial, and it almost goes without saying that most GIS are unable to handle such flow data easily and consistently. However, in the development of these models, incomes, rent levels, and related financial data such as travel costs, fares, derived measures of the value of time and so on, may be required. This type of data is difficult although not impossible to obtain, and is sometimes provided indirectly through various proxies but it is rare to see GIS which handle such data. Furthermore, in the development of microeconomic models, data on various types of consumer and producer preferences are important and the data structures and estimation techniques required in their interpretation are well beyond the domain of any present GIS in terms of the representation of such data and its subsequent analysis.

Data pertaining to the way equilibrium in various land markets is achieved are also useful and this implies that any data system useful to such modeling would be at least quasi-dynamic in form. As we have already seen, GIS are not well-adapted to dealing with temporal data. These types of model also require data which relate activities such as counts of population and employment of various types to counts of physical data such as housing, to economic data such as incomes and rents, and to abstract data such as utilities. In other words, these models require data from different sources which must be dimensionally consistent in terms of their modeling but the whole question of developing GIS with functions which ensure consistency over different types and dimensions of data has hardly been broached. From what we have already said in previous sections, the current generation of GIS do not contain any functions which would enable the sorts of model we are describing here to be estimated and used in prediction or prescription. In fact, the only way at present to use GIS to support such modeling would be to transfer relevant input and output of data between such systems and models, and perhaps to use the systems to check data for consistency, to derive new variables for use in modeling, and of course to provide useful media for graphical communication through visualization.

We will continue here to dwell on models of urban subsystems and then indicate how more comprehensive models might impact on GIS. Demographic models are well developed in planning in terms of the natural processes of aging but have not been developed with any rigor in a spatial context. Macroeconomic models of the urban and regional system based on input-output structures with functional and spatial linkages form the basis of the economic subsystem in locational modeling while a variety of lesser techniques based on locational quotients, shift-share representations and such like pervade the development of urban economic analysis in a practical context. The major problem with such models is that they have been developed and continue to exist separately from spatial models based on interaction through space where location is resolved through various land and transport markets.

There has in fact been substantial speculation on the ways in which these demoeconomic sector models might be integrated with location models of housing, transport and retail markets although progress in linking such systems functionally has been slow and links which do exist are pragmatically structured (de la Barra, 1989; Batey and Madden, 1982; Wegener, 1982). The data requirements of such models too are not those which are obviously amenable to representation in a GIS in that both demographic and economic models are only implicitly spatial with their categorization across age cohorts, occupational and industry types not usually disaggregated to the map areas which form the basis of GIS. Where space is considered explicitly in demographic models, it is in terms of migration defining temporal-spatial flows which as we have seen, is data which is difficult to handle in the current generation of GIS. The same problem of representing spatial linkages in economic models through commodity flows also limits the usefulness of GIS for these economic models.

Since the 1960s, there have been many attempts in planning to build and apply more general urban model structures which couple various partial system models together. We have already noted the idea of integrated models in which demographic and

economic coupling provides the basis for partial spatial modeling although earlier and more general attempts in which economic and demographic structures are used to weave the residential, workplace and retailing subsystems together in functional terms have been widely applied as developments of Lowry's (1964) original Pittsburgh model (Batty, 1976; Putman, 1983, 1992). These types of model structure have been extended to deal with transportation modeling too (Webster et al., 1988) while various dynamic extensions to such models exist (Mackett, 1983). Recently there have been several attempts to integrate demographic economic, travel demand, housing market and spatial interaction models within more general model structures which in turn have been embedded within dynamic frameworks (Bertuglia, Leonardi and Wilson, 1990).

The data requirements of such models can be formidable but the problems of linking them to GIS are no different from those indicated above. GIS find it difficult to deal with flow and temporal data, and consequently such models have been rarely linked to such systems. However, the real problem of extending GIS to embrace the functionality required in such modeling relates to the fact that current GIS have not been designed with any iterative capabilities in mind when it comes to extending their functions to deal with equation solving and estimation. Invariably, urban models which seek to model some equilibrium must be solved iteratively, the iterations being some analogue of the way markets clear, of the time involved in moving towards a steady state, or simply of the need to solve many simultaneous nonlinear equations. The idea that GIS might be constructed around such processes has barely been considered to date (Couclelis, 1991).

In the sequel, we will begin to describe some of the difficulties of using optimization models in relation to GIS. However, it is worth noting that GIS are quite well adapted to combining variables in spatial form and one of their main functions is in overlay analysis. The sorts of implicit model which lie behind such operations are somewhat rudimentary although overlaying with a view to finding map areas which meet given spatial constraints and which seek areas where the potential or utility for development is greatest, is a process which is akin to formal optimization. Other developments in which location-allocation models might be embedded or linked to GIS are being actively explored at present in much the same manner that transportation models are being linked to such systems (Densham, 1991). In one sense, it is easier to extend GIS structures to encompass optimization modeling than the more complex predictive system modeling which draws from substantive discipline areas such as economics. However, in general at present, linking GIS to system models of all kinds is an activity which has hardly begun with few urban models taking on the vestiges of GIS and vice versa. Nevertheless, this is an active area of research and there is likely to be some considerable progress in this area over the next decade (Brail, 1990).

Finally we need to mention the relationships between GIS and other system models based on ecology and energy which are relevant to urban and regional planning. These types of models are based more on the functioning of non-man-made systems than on social systems although there is an essential interaction between both types which is always problematic. In fact, GIS are better adapted at the present time to dealing with models of physical than socio-economic systems in that systems whose main representation is physical in form can be more easily represented in GIS than the non-physical whose characteristic variables are often more abstract. For example, it is easier to see how systems whose data pertains to the surface of the earth such as climate models, models of energy use and pollution, models of global warming, of environmental functioning and so on can draw on the concepts of GIS although the same problems alluded to above in terms of the substantive functioning of such systems dominate their formal use in the context of GIS.

So far in this paper we have been dwelling on the problems of linking models to GIS with the emerging conclusion that such systems and models are not easily embedded within one another. In other words, extending the functionality of GIS to enable complex models to be a part of such systems does not seem like a useful development in other than the most specialist of applications. The implication is that where GIS is to be used to support modeling, such systems should be mainly based on using their representational and graphic capabilities to store, derive and communicate data rather than extend their usage to modeling. In the same way, it appears that formal models should not attempt to be embedded or embellished with GIS-like functions but should use the power of GIS for purposes of communication and presentation. However, none of this preempts the possibility that new forms of GIS are likely to be required which are built around models rather than data. For example it is easier to build urban models in spreadsheet rather than GIS media for such spreadsheets offer extensive functionality in one-one correspondence with their data storage capabilities. GIS-like spreadsheets might find a role in planning support as frameworks for formal modeling, along the lines being developed for using standard spreadsheets for urban models and related planning techniques (Brail, 1987; Klosterman, Brail and Bossard, 1992).

VI. THE NATURE OF SPATIAL PLANNING AND MANAGEMENT

Planning is the premeditation of -action; management is the direct control of action. Decision-making considers the conclusions of planning, and translates them into norms and instructions which govern the management process. It is thus evident that management requires current knowledge of the state of the social or physical system in and on which it is acting. Such current knowledge is based directly on current data, organized in an information system. Frequently the management functions involve transactions which are entered into the information system more or less in real time. Examples are airline reservations, banking accounts, real estate assessment, utility maintenance, and development permit processing. The last three of these management

functions deal with matters which are geographically distributed, and they ordinarily require information which is geographically organized--so that they must be backed up by a form of geographic information system (Harris, 1989).

In all of these cases the need for a fully dedicated system in the management sense must be weighed against the need for some form of integration with other organizational information and functions and for providing direct feedback to planning and decision-making. Airline reservations, for instance, demands such massively focussed concentration that it is virtually a stand alone system. The geographic features of its environment (such as the impact of weather on schedules) and the feedback to organizational decisions such as market segmentation and pricing, though intimately related to reservations, are handled externally to the system, which provides information to them skimmed from its own operation. The degree of integration of the spatial management functions with GIS poses similar issues, which are still being investigated experimentally.

Spatial planning offers a substantial contrast to management. The concerns of planning are far more long term. A major consideration of planning is the avoidance of unintended consequences, while pursuing intended goals. Both intended and unintended consequences arise out of the propagation of effects throughout the system for which planning has been undertaken, over time, space, and function. Plans for large but very localized transport improvements, for instance, have effects which spread spatially through an extensive area, which take a long time to mature, and which strongly influence other subsystems like residential, commercial, and industrial location. In order to assess these consequences, planning needs methods for making conditional predictions based on alternative hypothetical decisions. Both the research establishing the capability to make such predictions, and the mechanisms by which scores of predictions can be made and examined, call for extensive computational resources and sophisticated simulation modeling. While this process involves geographic organization of the data, and deals with spatial relations, it cannot cope with constant shifts of geographic definitions and concepts. It operates far more effectively with a single predefined area system, or a carefully planned and partially hierarchical system in which computation at different scales with aggregation and disaggregation are possible for well-defined purposes.

This process is intended to answer very general "what-if" or hypothetical questions, and by changing the hypotheses and sifting the results to arrive at recommendations for many coordinated aspects of future development. Some versions of GIS have claims made about their ability to answer similar questions, but on examination the support for these claims proves disappointing. Most what-if questions which GIS can deal with depend on overlay comparisons, proximity measures, and "buffering", which measures the level of events, activities, or populations within a band or ring defined by distance from a geographic entity. They do not deal with large scale simulation and the effects of interaction at a distance; models involving these concepts require very extensive computations, and the systems which use them must be very specifically directed to improving the speed of this work. GIS turn out to be directed to very different problems. These views now require more specific development, which we approach through a discussion of the broad character of a possible planning support system for spatial planning and decision-making.

VII. THE REQUIREMENTS OF PLANNING SUPPORT SYSTEMS

Up to this point we have reviewed the growing capabilities for PSS, in some sense comprehending and dealing with the urban and regional environment, both natural and man-made. We have seen that methods are in place for recording, storing, and presenting geographic information from a variety of sources in a reliable, accurate, and usable form. We have shown that models are available which replicate the functioning and often the dynamic development of systems with multiple geographically distributed components and actors performing a variety of functions, pursuing a variety of ends, and obeying numerous social, physical, and biological laws. Finally, we have shown how in many cases the behavior of the actors or the analysis of possible actions leads to some sort of optimal performance by or policies for parts of certain systems. This review demonstrates that most of the elements which are needed for a planning support system in urban and regional affairs are already at hand, but not yet in a fully integrated form. The use of appropriate data and computational schemes in GIS is a special weakness. It is our purpose in this section to define more exactly the desirable content and features of a planning support system, and to focus attention on the shortfalls in current practice.

There is obviously a substantial overlap between spatial planning, as it is undertaken in City and Regional Planning, and Geography. Both disciplines (or professions) rest on the study and analysis of spatially distributed systems, and of their growth, development, and change. At the same time, planning goes further, in requiring the management of these systems and the- anticipatory premeditation of action regarding them. These activities are akin to policy making, and the need for them arises in both public and private undertakings, in urban and rural settings, and in man-made and natural systems. With respect both to replicating system behavior and to anticipatory planning, Planning and Geography simultaneously draw some ideas from Economics and are somewhat in conflict with it (Harris, 1991b). The principal conflict, not yet examined, arises over the claim of many economists that market forces alone (perhaps with some remedial legislation to tax, subsidize, or regulate such irregularities as externalities) can automatically drive behavior to appropriately optimal conclusions. If this were so, then planning would be largely irrelevant and economic geography in certain aspects redundant, because market forces would determine the shape of geographic development and the optimal allocation of resources. It could thus be claimed that a competitive equilibrium is both the best plan and the best explanation for human geographic distributions.

This view suffers from some obvious limitations. We have to assume that human and institutional behavior follows closely the description given in microeconomics. Spatial distributions and spatial separation call for a redefinition of equilibrium, as does the long-term permanence of investment in buildings, structures, and improvements to the land. Most important, however, is the many-sided situation in which public investment and spatial separation together lead to economies of agglomeration and of scale, large works are indivisible, reciprocal externalities cannot be disentangled, and both private production and public goods have large fixed costs so that marginal cost is below average cost. All of these situations lead to lumpiness, full or partial monopolies, and the possibility of multiple local equilibria in the allocation of resources and the development of locational patterns. Even if all possible economic measures have been taken to ensure that equilibrium states are locally optimal, multiple stable equilibria imply multiple optima.

The existence of multiple possible local equilibria has enormous consequences for the actuality and the theory of geographic location and spatial planning. Any given local optimum may be far from an **optimum optimorum**, so that a high level of benefit resulting from the play of market forces is either a matter of accident, or a matter of planning, or both. Problems of prediction and economic justification which arise out of chaos in the environment (that is, the unpredictability of complex deterministic systems) are exacerbated by the possibility of catastrophes, or sudden discontinuities in development (Bertuglia, Leonardi and Wilson, 1990). These discontinuities arise, in a space of continuous responses to change, out of the folding of the response surface which corresponds with multiple optima. In computational terms, it is exactly this multiplicity of local optima which makes the problem of global optimization completely intractable. In this situation, there are two principal requirements for planning, which devolve onto any planning support system:

First, since system optimization (which equates with the automatic generation of plans) is impossible, the search for good plans must be by way of an informed process of trial and error which generates alternatives and prepares them for testing. This is often called sketch planning.

Second, planning and policy making need extensive tools for tracing out the consequences of alternatives, since otherwise there is no way to compare alternatives on the basis of their costs and benefits, and no way to look for means of improving or replacing alternatives.

These tools can now be provided in a computer-based environment, using models which simulate the development, performance, and equilibrium properties of hypothetical systems. However, present-day information systems do not permit us to trace these consequences far enough over time, space, or function.

In addition to these two basic requirements, there are others which are related to them, to the process of planning, and to the state-of-the-art of computer simulation and computer-based information systems. Some of these may be sketched under a variety of headings. The level of sophistication of the computer systems is strained by several implicit requirements and we will list these as follows:

We have to be able to trace the effects of all possible measures which may be included in a plan, and their combinations.

We have to be able to reproduce all effects which may be of interest in evaluating the achievement of any desired objectives--not only efficiency and economic effectiveness, but equity, amenity, diversity, environmental protection, and many others.

Simulations must encompass very large systems because planning must avoid unintended consequences, which are generated over space, time, and function in ways which escape narrowly focussed evaluations.

The demands on geographic and related information systems are extensive; these are:

The geographic content of spatial decision-making is essential, and must be stored in terms which are relevant to these decisions and the associated models - such as quantitative measures of interaction time and cost.

Visually accessible and in some cases interactive displays of inputs and outputs are needed because visual effects and synoptic overviews of relationships are essential to planning (Buttenfield and McMaster, 1991).

Similar requirements extend to public information, public education, and public participation in the planning process and the information system must interrelate actively with simulation methods which are used to trace the effects of plans.

Planning support systems (PSS) will operate in a changing environment, in which they will be put to many different uses, and in which experience should be rapidly accommodated in expanding and altering the capabilities of the system:

A PSS should be designed to extend to the outer envelope of potential and feasible uses, from planning management through functional planning (such as transport, housing, retail trade, and environmental conservation), to comprehensive planning and zoning.

A PSS should be especially cordial to the entering of new plans or modification of old ones, and at various levels of specificity, in the process of sketch planning.

The planner should be supported in experimental approaches not only in generating plans themselves but also in planning method, in the definition and measurement of the objectives of plans, and in the interpretation of behavior and the type and style of models to be used. Therefore PSS should be available for public use, both as to methods and as to data.

A PSS should accommodate research, allowing the introduction of new methods of simulation, new sources of data, new flows of work, and new measurement and presentation of outputs.

The use of the systems should as far as possible be self-teaching.

They should be adaptable to a wide variety of situations, levels of information, size and type of area being planned, and styles of planning.

and

The models and methods embodied in the PSS should be understandable to the user and in Einstein's (1955) immortal phrase be "...as simple as possible, but not more so."

VIII. OPTIMIZATION AND PLANNING

It is possible, but not perhaps appropriate to this paper, to turn all of the foregoing into a set of specifications for producing a PSS. This is an act of research design in which we are interested, but for which we see the importance of numerous centers of design and innovation. Having said all this, we may still turn our attention to a few issues which will need to be debated, tested, and constantly reviewed in initial designs and their later revisions, and which our own experience has called forcibly to our attention. An issue regarding the employment of economic principles in modeling which is often of major importance is the representation of the behavior of people, households, and firms. Partly this issue turns on the concept of 'economic man' and the importance of non-economic motivations, and partly it turns on the uniformity or diversity of behavior. These issues are linked. While economic forces are important, they may not be wholly determinative of behavior; and while there is much uniformity in modern life (and indeed in all social affairs), there is some diversity which may not be economically explainable. The paradigm of free enterprise itself contradicts the rules of micro-economics and their drive toward uniformity. We believe for our purposes in the use of discrete choice or gravity models to represent this diversity, but we recognize that it can be reproduced by devices like the application of linear programming to a succession of choice situations (Anas, 1983; Wilson, et al., 1981).

Our insistence on a flexible and even skeptical attitude toward economic doctrine is not to be taken too far. We recognize the very great importance of the economic consequences of plans both for the public polity and for the beneficiaries of plans. Indeed, we regard market measurements of plan performance, when they can be made available, as being of very great value, and we will discuss optimization by way of market forces below. At the same time we continue to recognize the public (and private) importance of noneconomic bases for decision, and feel that these have an inescapable role in planning. Issues of multiple criteria for choice amongst plans can however become very troublesome. As the number of criteria increases, standard methods become combinatorially explosive (Harris, 1967). Some criteria tend to evade quantification. It is a fact of political life that planners do not make final decisions, and that the public, their representatives, and other decision-makers often have undeveloped or unexpressed criteria which become effective only in the face of actual or imagined choices. Such unknown criteria by definition cannot be part of any systematic evaluation, and their existence is a powerful argument for the preparation of alternative plans or schemes, with closely comparable measurable values.

This precept, which has its roots in traditional land-use planning and in the arts, runs entirely counter to the rules of science and of economic optimization. In science (as in religion) there is generally only one correct theory to explain a given phenomenon, and in economics a unique optimum is reached by a slow ascent to the summit, so that it is very similar to other close-to-optimal solutions. This situation changes drastically when there are many local optima. In the solution, for instance, of the Koopmans-Beckmann problem of quadratic programming (which fits the problems of factory layout and new town zoning) there may be many local optima which differ greatly from each other yet have very similar values. This can be verified by experiment, with well-defined specifications for local optima and for measures of the values of arrangements and the differences between them. The

important consequence is that certain very different plans and policies (for example, for urban transport or for health care) can potentially be clearly discriminated between not on the basis of expected performance, but only on the basis of aesthetic, moral, or political considerations.

The generation and testing of a large-scale and complex plan by the general methods we have outlined is feasible but potentially difficult. The rapid growth of computing power and the potential improvement in methods will reduce this difficulty. However, the process of finding a number of alternative good plans which are in the nature of possible local optima is apt to be more difficult. It is at present and for the foreseeable future more in the nature of an art than of a science. We believe that the key to reducing this difficulty and improving the art lies in a division of labor between the planner and the computer. The planner should be in a position to generate many plans which are in their fundamental features structurally different, but in which a minimum number of specific decisions have been taken. The computer should be able to undertake the detailing of the plans as required.

The essential way in which this should be done is by a set of design or planning rules which the computer would apply. These might have many different forms, among which the planner could choose in operating the system. One of the most immediately attractive is an optimizing procedure which determines locations and allocations for a functional subsystem according to one of several predetermined methods. This approach evades the difficulty in general system optimization by dividing the larger system into subsystems which can be separately optimized once certain planning decisions have been taken (Simon, 1969). These planning decisions are parts of the planner's structural scheme, or they result from the prior optimization of some other subsystem. Many of these optimizations would often use market simulations and could produce economic measurements of performance. A few examples will distinguish some of the varied approaches to this problem.

Good economic models exist (as we have discussed) of house choice and housing markets, for which rents or prices are endogenous and the state of the market determines the choices and the utility levels of the households of different types and with different levels of income, as they result from market clearing. This model can be used in a variety of modes: with general equilibrium or with incremental changes; with a preexisting or a built-to-order housing stock; with zoning or with market determinations of housing type and lot size; with taxes, subsidies, travel costs, distributed employment, neighborhood characteristics, and other influential factors. If there are no built-in externalities such as social preferences in location or advantages in agglomeration, this model leads to a unique equilibrium which is optimal given the surrounding circumstances. Obviously it can be used in many different ways as a market model, and it can be modified to respond to various forms of public control and allocation in a socialist or mixed market, and to measure their impacts.

Retail trade and services can be located by many different types of models, many of which assume some sort of balance between the advantages of shopping in larger centers or establishments and the disadvantages of traveling longer distances. The location of shopping under these models is often not mediated by a price mechanism, but measurements of the costs of operation and the levels of consumer satisfaction can be devised. Still other classes of activity such as facilities for public safety, health, education, and some services like post offices may be located according to optimizing procedures which take into account non-economic standards like response time, suitable size of facility, user convenience, and so on. These facilities must be located in relation to the present and prospective demand for services, and are only indirectly controlled by economic considerations. The techniques available for optimizing their location come from Geography, Operations Research, and functional engineering and planning practice.

We are aware that the coordination of facilities such as these with a geographic information system so as to provide a planning support system of real utility is a major undertaking. It will involve the coordination of existing methods in a new software environment, and use of such a PSS should and will lead to the recognition of a need for new and presently unforeseen inventions and changes. As we have tried to indicate, it should lead to an environment in which research and practice are brought much closer together, and in which many more people in various walks of life, professions, and disciplinary fields become more deeply involved.

IX CONCLUSIONS

Perhaps the best way to approach the need to draw our conclusions together is to review, in the light of what we have said so far, the immediately feasible role of a geographic information system in the operation of a planning support system. This can then be contrasted with the work of the PSS itself, and some indication of future cooperation and possible convergence of the two streams may be spelled out. Lying behind the work of GIS and PSS in regional and metropolitan planning, there must be another system which is essentially non-geographic with respect to the region being studied, but which is likely to be geographic as to the situation of the home region in a system of regions, states, and nations. Such a predictive system would deal with future trends in population growth and age composition, in- and out-migration, family formation, industrial composition, productivity, income, and many other factors disaggregated by population and industry groups, but not usually by areas within the region. While this system is needed to support planning, we do not here consider it part of a PSS.

The GIS in this partnership would then control the definitions of geographic areas, of channels of communication, and of point or small area locations. It would be used to define a set of primitive areas at the lowest level of disaggregation which would be used by the PSS. Methods of GIS functionality could be used actively by the PSS to aggregate primitive areas into larger areas in a hierarchy. The GIS or its methods would be used to produce maps and charts summarizing the work of the PSS, using these defined or definable area systems. The contribution of the GIS could go far beyond this. The overlay capabilities of the GIS could be used to generate variables relevant to the work of the PSS but not directly accessible to it, such as the average slope or elevation of each area, or the proportion of areas in flood plains. The GIS should be able to extract other information and features, such as the number and condition of structures in each area, or the description of a hierarchy of movement channels to be used in transport analysis or utility planning. The present state of the region by small areas could be specified in terms of land and facility valuations, population, employment, and any other available attribute data presently known to the GIS.

The PSS by contrast would be largely concerned with design and simulation. It could readily accept the input of new facilities and of new regulations which would affect the functioning of the region and the behavior of its occupants, and thus would be appropriately used in simulations. Most importantly, it would be able to act on inputs of population and industrial change, and to trace out the interactions of these changes with the changes in facilities and policies which were being tested. The simulations and design modules of the PSS would deal with residential, commercial, and industrial location, with the planned provision of public facilities, and with the provision of needed utilities or the effects of levels of utility services. Underlying much of the locational simulation, there would be a model of transport interaction which would accommodate policies with regard to mass transit, parking, and transport fees, and which would simulate congestion and the transport response to it. Land use responses would appear in the modeling of locational behavior. An important feature of a PSS would be its data management capabilities, which would deal with multiple future time periods and multiple alternative plans and their outcomes. This multiplicity of files of attribute information could swamp presently available GIS, and might carry the danger of compromising their data integrity.

The nature of a PSS need not be specified in detail for us to see that the demands of its design and operation are very severe. This suggests that progress could be made more rapidly if prototype PSS were to be developed independently of GIS, but in parallel with it. We believe that the arguments of this paper have made such a development not only desirable, but inevitable. Neither the arguments nor the realization of such a development, however, should be interpreted as foreclosing the ultimate inclusion of PSS capabilities within GIS. However, the present lack of available PSS capabilities leads planners to be ignorant of their potential, and this leads to a lack of demand which discourages the vendors of GIS from producing suitable PSS capabilities. Thus their potential realization is blocked. In short, development would probably be more rapid and of higher quality if GIS and PSS followed independent but loosely coupled paths of development for some time to come. To recognize the different character of the requirements for the operation of the two systems in a computer environment does not preclude the possibility that means may be invented to couple them more closely. At this stage, we believe that independent development will tend to define this problem with greater clarity/ and thus to lead more rapidly to such a resolution if one is available.

X. REFERENCES

- Anas, A. (1982) Residential Location Markets and Urban Transportation: Economic Theory, Econometrics and Policy Analysis with Discrete Choice Models Academic Press, New York.
- Anas, A. (1983) Discrete Choice Theory, Information Theory and the Multinomial Logit and Gravity Models, Transportation Research B, 17,13-23.
- Anas, A. (1987) Modeling in Urban and Regional Economics, Harwood, New York.
- Barra, T. de la (1989) Integrated Land Use Transport Modelling: Decision Chains and Hierarchies, Cambridge University Press, London.
- Batey, P. W. J. and Madden, M. (1982) Demographic-Economic Forecasting within an Activity-Commodity Framework: Some Theoretical Considerations and Empirical Results, Environment and Planning A, 13, 1067-1083.
- Batty, M (1976) Urban Modelling: Algorithms, Calibrations, Predictions, Cambridge University Press, London.
- Batty, M. (1979) On Planning Processes, in B. Goodall and A. Kirby (Editors) Resources and Planning, Pergamon Press, Oxford, UK, 17-45.
- Batty, M. (1989) Urban Modelling and Planning: Reflections, Retrodictions, and Prescriptions, in B. MacMillan (Editor), Remodelling Geography, Basil Blackwell, Oxford, 147-169.

- Batty, M. (1990) Informative Planning: The Intelligent Use of Information Systems in the Policy-Making Process, in H. Sazanami (Editor) Critical Success Factors: Key to Use of Information Systems-Technology in Local-Regional Planning, United Nations Centre for Regional Development, Nagoya, Japan, 307-356.
- Batty, M. (1991) Geographic Information Systems: GIS in Urban Planning and Policy Analysis, A Paper Presented at the Study Group on Regional and Global Economic Integration, Development Planning, and Information Technology, United Nations Centre for Regional Development, Nagoya, Japan, 11th-14th November 1991.
- Beckmann, M. J. (1969) On the Distribution of Urban Rent and Residential Density, *Journal of Economic Theory*, 1, 60-67.
- Ben Akiva, M. and Lerman, S. R. (1985) *Discrete Choice Analysis: Applications to Travel Demand*, The MIT Press, Cambridge, MA.
- Bertuglia, C. S., Leonardi, G., and Wilson, A. G. (Editors) (1990) *Urban Dynamics: Designing an Integrated Model*, Routledge, London.
- Birkin, M., Clarke, G., Clarke, M. and Wilson, A. G. (1990) Elements of a Model-Based Geographic Information System for the Evaluation of Urban Policy, in L. Worrall. (Editor) *Geographic Information Systems: Developments and Applications*, Belhaven Press, London, 132-162.
- Brail, R. K. (1987) *Microcomputers in Urban Planning and Management*, Center for Urban Policy Research, Rutgers University, New Brunswick, NJ.
- Brail, R. K. (1990) Integrating Urban Information Systems and Spatial Models, *Environment and Planning B*, 17, 417-427.
- Brewer, G. D. (1973) *Politicians, Bureaucrats and the Consultant: A Critique of Urban Problem Solving*, Basic Books, New York.
- Buttenfield, B. P. and McMaster, R. P. (Editors) (1991) *Map Generalization: Making Rules for Knowledge Representation*, Longmans, London.
- Clercq, F. Le (1990) Information Management within the Planning Process, in H. J. Scholten and J. C. H. Stillwell (Editors) *Geographical Information Systems for Urban and Regional Planning*, Kluwer Academic Publishers, Dordrecht and Boston, MA, 59-68.
- Couclelis, H. (1991), Geographically Informed Planning: Requirements for Planning Relevant GIS, *Papers in Regional Science*, 70, 9-20.
- Dangermond, J. (1990) Geographic Information System Technology and Development Planning, *Regional Development Dialogue*, 11, 1-14.
- Densham, P. and Rushton, G. (1988) Decision Support Systems for Locational Planning, in R. G. Golledge, and H. Timmermans (Editors) *Behavioural Modelling in Geography and Planning*, Croom Helm, London, 56-90.
- Densham, P. (1991) Spatial Decision Support Systems, in D. J. Maguire, M. F. Goodchild, and D. W. Rhind (Editors) *Geographical Information Systems: Principles and Applications*, Longmans, London, 403-412.
- Ding, Y. and Fotheringham, A. S. (1992) The Integration of Spatial Analysis and GIS, *Computers, Environment and Urban Systems*, 16, forthcoming.
- Einstein, A. (1955) *Essays in Science*, Philosophical Library, New York.
- Forrest, E. (Editor) *Intelligent Infrastructure Workbook: A Management-Level Primer on GIS*, A-E-C Automation Level Newsletter, Fountain Hills, AZ.
- Fotheringham, A. S. and OKelly, M. E. (1989) *Spatial Interaction Models: Formulations and Applications*, Kluwer Academic Publishers, Boston.
- Harris, B. (1959) Plan or Projection: An Examination of the Use of Models in Planning, *Journal of the American Institute of Planners*, 25, 265-272.

- Harris, B. (1967) *The City of the Future: The Problem of Optimal Design*, Papers of the Regional Science Association, 19, 185-195.
- Harris, B. (1989) *Beyond Geographic Information Systems: Computers and the Planning Professional*, journal of the American Planning Association, 55, 85-90.
- Harris, B. (1991 a) *Planning Theory and the Design of Planning Support Systems*, A Paper presented to the Second International Conference on Computers in Planning and Management, Oxford, 6-8 July, 1991.
- Harris' B. (1991b) *Planning, Geography and Economics in Spatial Decision-Making*, A Paper presented at the Department of Geography, State University of New York, Buffalo, NY, 26 October, 1991.
- Harris., B. and Wilson, A. G. (1978) *Equilibrium Values and Dynamics of Attractiveness Terms in Production-Constrained Spatial-Interaction Models*, Environment and Planning A, 10, 371-388.
- Huxhold, W. E. (1991) *An Introduction to Urban Geographic Information Systems*, Oxford University Press, New York.
- Klosterman, R., Brail, R. K. and Bossard, E. G. (Editors) (1992) *Spreadsheet Models for Urban and Regional Analysis*, Center for Urban Policy Research, Rutgers University, New Brunswick, NJ.
- Lee, D. B. (1973) *Requiem for Large-Scale Models*, journal of the American Institute of Planners, 39, 163-178.
- Lowry, I. S. (1964) *A Model of Metropolis*, RM-4035-RC, The RAND Corporation, Santa Monica, CA.
- Mackett, R. (1983) *The Leeds Integrated Land-Use /Transport Model (LILT)*, Supplementary Report 805, The Transport and Road Research Laboratory, Crowthorne, Berkshire, UK.
- Manheim, M. L. (1986) *Creativity-Support Systems for Planning, Design and Decision Support*, Microcomputers in Civil Engineering, 1, 3-14.
- Penzias, A. (1989) *Ideas and Information: Managing in a High-Tech World*, W. W. Norton and Co., New York.
- Putman, S. (1983) *Integrated Urban Models: Policy Analysis of transportation and Land Use*, Pion Press, London.
- Putman, S. (1992) *Dynamic Urban Transport and Location Models*, Pion Press, London, forthcoming.
- Shubik, M. (1979) *Computer and Modeling*, in M. L. Dertouzos and J. Moses (Editors) *The Computer Age: A Twenty Year View*, The MIT Press, Cambridge, MA, 285-305.
- Simon, H. A. (1969) *The Sciences of the Artificial*, The MIT Press, Cambridge, MA.
- Webster, F. V., Bly, P. H., and Paulley, N. J. (Editors) (1988) *Urban Land-Use and Transport Interaction: Policies and Models*, Avebury, Aldershot, Berkshire, UK.
- Wegener, M. (1982) *A Multilevel Economic-Demographic Model for the Dortmund Subregion*, Sistemi Urbani, 4, 371-401.
- Wilson, A. G., Coelho, J. D., MacGill, S. M. and Williams, H. C. W. L. (1981) *Optimization in Location and Transport Analysis* John Wiley and Sons, New York.