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SPATIAL INFORMATION SYSTEMS: DESIGN, MODELLING, AND USE IN PLANNING

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ABSTRACT

This paper focuses on the role of spatial information systems in regional and urban planning. Experiences on the design, modelling and use of such systems are briefly commented upon. Special attention is then devoted to the potential of GIS. Next the question of designing tailor made information systems for planning is dealt with. A triple layer methodology for integrating information systems in planning models is proposed, with a particular view on three steps: conceptual reflection, prototype experimentation and operational software design. Next, the link between information systems and spatial planning models is dealt with. The paper is concluded with a discussion on choice trajectories for optimum planning uses of a given data input vis-á-vis optimum data inputs for given planning uses.

1. SPATIAL INFORMATION SYSTEMS AND PLANNING

Information systems and planning have in the past decade become twins. Strategic urban and regional planning (including land use and transportation systems planning) requires the design and use of tailor-made information systems. Such spatial information systems (incorporating also data management systems and simulation models) may become effective planning tools if the following conditions are satisfied:

- the presence of a flexible and user-friendly information systems model for strategic process planning and policy making, which is fairly robust under various developmental conditions of the spatial system concerned.
- an integration of recent software advances, notably in the field of geographic information systems (GIS), with modern tools for evaluating urban and regional development projects or programmes.
- the provision of a flexible decision support framework (including monitoring mechanisms, early warning systems, cost-benefit analysis, multicriteria analyses, and simulation experiments) which is able to assist planners and decision-makers in making strategic choices in an uncertain environment.

In recent years, elements of this approach have been developed separately in various cases (for instance, decision support and expert systems for urban and environmental planning, GIS for spatial referencing), but a uniform, integrating and coherent information systems model framework aiming at pro-active planning and policy-making is lacking. The development of GIS systems is able to stimulate advanced information systems technologies by incorporating sophisticated planning tools (software, models) in strategic phases of planning,(cf. Fedra and Reitsma, 1990). The need for a co-evolutionary pathway between technical methods (includingGIS) and planning is becoming increasingly evident.

Various promising developments can be recorded in this new field. In the international arena, the attempts of ISGLUTI (International Study Group on Land Use/ Transport Interaction) constitutes probably the most recent effort for advanced urban and regional planning. Several software programmes are now available which can handle land use and transport interactions (e.g., MEP, DORTMUND, LILT, ITLUP, CALUTAS).

As far as country specific activities in this field are concerned, some interesting examples of integrated information systems models can be mentioned here.

- France has in recent years seen remarkable progress in the area of computer - aided planning (CAP). Good examples can be found amongst others in Lyon, where multi - media databases and multi - media data modelling have become part of urban planning processes. Also in the field of image encoding and image databases as well as of gametic information systems new developments have taken place. Particularly interesting are also recent advances in the area of interactive videodisc systems for urban management.

- The Netherlands has built up a strong tradition in the area of urban, regional and transportation planning. In many cases, computerized evaluation tools (e.g. multicriteria analysis) have played a dominant role as a structural communication vehicle for strategic planning. In recent years these tools have been extended by the use of GIS, whilst increasingly DSS types of planning approach (including expert systems) have come into being, notably in the environmental field.
- The U.S.A. has witnessed in recent years an avalanche of GIS applications, particularly in urban planning. A standard example is the city of Tacoma, which has decided to develop its whole planning infrastructure jointly with automated and integrated data bases for all urban planning sectors (e.g. land use, built environment, firestations, post offices, etc.). Similar developments are taking place in Chicago and Los Angeles.

The previous illustrations of applications of spatial information systems are not exceptions, but they reflect the broad penetration of such systems in urban and regional planning practice.

Information has become a key variable in planning. In the post-war period, many countries have experienced an information explosion. The introduction of computers, micro-electronic equipment and telecommunication services have paved the way for an avalanche of information, not only for scientific research, but also for information transfer to a broader public and for planning or policy purposes (Burch et al. 1979, De Man, 1989). Several reasons may explain this information explosion in planning and policy-making (Nijkamp and Rietveld, 1983, Nijkamp, 1988):

(i) our complex society needs insight into the mechanisms and structures determining intertwined socio-economic, spatial and environmental processes;
(ii) the high risks and costs of wrong decisions require a careful judgement of all alternative courses of action;
(iii) the scientific progress in statistical and econometric modelling has led to a clear need for more adequate data and information monitoring;
(iv) modern computer software and hardware facilities (e.g. decision support systems) have provided the conditions for a quick and flexible treatment of data regarding all aspects of policy analysis; and
(v) many statistical offices have produced a great deal of data which can be usefully included in appropriate systems.

In recent years, we observe the first signs that micro-electronics, informatics and telematics may dramatically alter western societies. In many countries, prosperity is no longer exclusively created by the production and use of manufactured commodities, but increasingly by the creation and sale of services, notably information-based and knowledge-based services (see also Cordell, 1985).

Effective and accessible information systems are vital to economic performance and strategic decision making. According to recent estimates, more than half of all jobs are already directly or indirectly related to the information and service sector, and this figure is likely to grow in the near future (Naisbitt, 1984). It is increasingly believed that advanced infrastructures for information exchange and services will be as dominant in the last decade of the twentieth century as waterway, rail and road transport infrastructures were in previous centuries.

The rapid development of digital and electronic technologies, for instance in the form of digital recording and transmission of sound and pictures, optical fibres for the high speed transmission information, super-fast computers, satellite broadcasting and video transmission, offers a new potential for sophisticated voice, data and image transmission. In the RACE programme of the European Community especially, many attempts are being made to stimulate and enhance research and development in information technology. Clearly, the development of hardware and software has to run parallel in this field.

The miniaturization of modern technology due to the development and widespread use of the silicon chip, has already led to drastic changes in transmission patterns of information. Distributed intelligence systems, not only at an intra-firm level but in the future also at a broader scale of European business interactions, are likely to change the face of our societies. CAD/CAM systems focusing on customization and economies of scope are already the predecessors of broader information technologies supporting scientific and economic progress. Thus in conclusion, information design and use has become a critical success factor for competitive planning efforts in western societies.

2. THE POSITION OF GIS

From a geographical viewpoint the trend toward advanced information systems has led to the design and use of geographical information systems (GIS). A GIS serves to offer a coherent representation of a set of geographical units or objects which - besides their locational position- can be characterized by one or more attributes. Such information requires a consistent treatment of basic data, from the collection and storage stages to the manipulation and presentation of the data.
All such information systems may be highly important for the planning of our scarce space, not only on a global scale (e.g. monitoring of rain-forest development), but also on a local scale (e.g. physical planning). Within this framework, spatial information systems are increasingly based on topology and combined with pattern recognition, systems theory, statistics and finite element analyses.
Such techniques are not only relevant for research; they may also act as information bases for physical planning. The Netherlands, for instance, has always been characterized by having a strict system of physical planning, to ensure proper management of its scarce space, and there is no doubt that various types of spatial information systems, that have been developed in recent years serve to provide a rational basis for policy decisions (e.g. Geertman and Toppen, 1990, Scholten and Padding, 1990). In general, a GIS enables four main functions : preparation, analysis, display, and management of geographical data. Preparation includes such functions as data collection, digitising point data, and editing. The purpose of the analysis function is to examine the data to create new data, with the aim of producing information. Display includes all operations which produce graphic output. Management is the handling of permanent alphanumerical and geographical data.

In the analytical functions of a GIS, the combination and selection of information on the basis of the geographical component is central. From the point of view of model construction and, more generally, from the point of view of quantitative-empirical methods, the specific GIS analysis methods supplement existing analysis techniques. They are, however, by no means a replacement of such methods. Models are stylized representations of reality, based on the logic of mathematics. GIS offers also a stylized picture of reality, using the fruits of modern computer technology and carthography and, above all, the integration of spatial and attribute data (c.f. Dueker, 1987).
Birkin et al (1987) speak of a necessary marriage between the model-based methods and the techniques from GIS to provide adequate tools to assist decisionmakers. They distinguish techniques for: transformation of data, synthesis and integration of data, updating information, forecasting, impact analysis, and optimization. They conclude that the two approaches have barely come together because of different historical traditions and research foci. A number of examples however, can be quoted in which the power of this integration is beginning to be used (Cliff and Haggett, 1988; de la Barra et al., 1984; Fedra, 1986; Fedra et al., 1987).

Figure 1 The hypothesis of the missing link

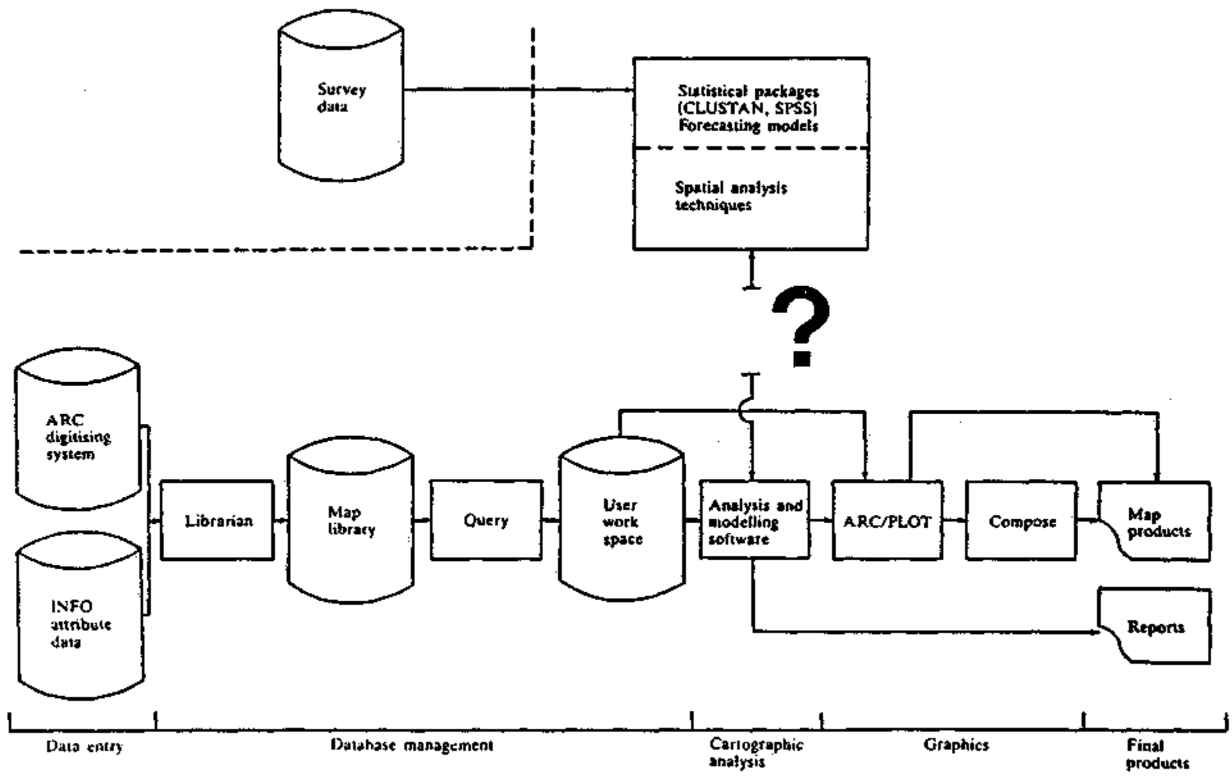


Figure 1, taken from Scholten and Padding (1990) provides a synopsis of the construction of GIS with, as already mentioned, the problem of the integration of the analysis techniques. Openshaw (1990) discusses four different routes to solve the problem: (1) write interfaces to statistical packages (i.e. SAS, GLIM or SPSS); (2) develop portable spatial analysis methods that can sit on top of a GIS; (3) create new procedures for incorporation inside GIS; and (4) incorporate GIS procedures within an analysis or modelling tool. However, in all cases, the really difficult part is not the interfacing of external software but the need to develop an appropriate tool box of spatial analytical procedures worth incorporating into GIS.

From the above, it can be concluded that not all users wish or need to make similar use of main GIS functions as is also shown in Table 1. It is clear that the further development of GIS should take advantage of this differentiated demand. It is also clear that potential users should specify more precisely which type of GIS best serves their interest.

On the basis of what has been established above, a multitrack development in GIS seems to offer the best solution for optimum use. Consequently, the most important development directions are in our opinion; an "integrated environment", a user-interface to overcome the different commando-languages of the different packages in use, farther-reaching interfacing with approprate spatial analytical procedures, the development of a "small and beautiful" tool for decisionmakers, and a high-accessibility information and query system for the public. The question of focused and tailor-made spatial information systems for planning will be discussed in the next section.

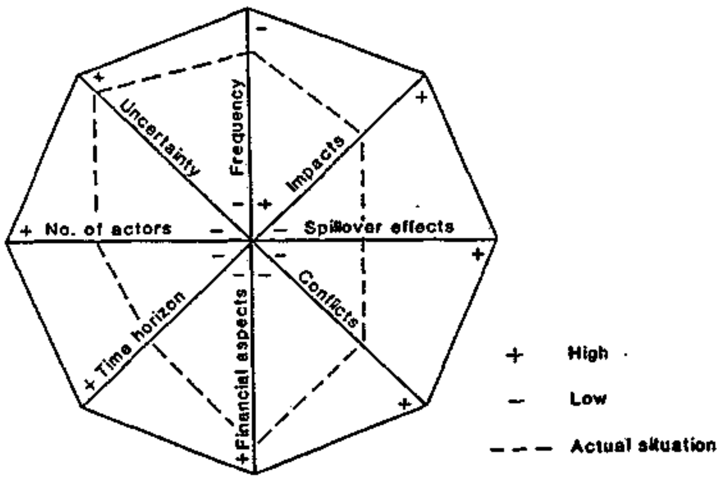
Table 1. Types of user demand for a geographical information system (GIS).

Type of User	Information demand	User demand	Type of GIS	Development
Information specialist	Raw data	Analysis Flexibility	Large Flexible	Links to other packages
Preparer of policy	Raw data and pretreated data (= information)	Analysis Good accessibility	Compact Manageable	Macrolanguages Interfaces to other packages
Policy decisionmaker	Strategic information	Good accessibility to users Weighting and optimisation models	'Small and beautiful'	User-friendly interface Key information
Interested citizen	Information	Good accessibility to users	'Small and beautiful'	User-friendly interface

3. SPATIAL INFORMATION SYSTEMS IN A PLANNING ENVIRONMENT

Spatial information systems are not a tool as such, but tools for improving the quality of planning and decision-making. The requirements posed on such systems depend on the specific nature of the planning problem concerned, but in general various generic criteria can be distinguished for assessing the claims of such systems (see also Figure 2, taken from Nijkamp, 1990). In Figure 2 the axes of the octagon measure the intensity of such claims as a result of a given feature of the planning problem at hand. The envelope reflects the highest possible claim; in reality an information system will take an intermediate position between the envelope and the origin.

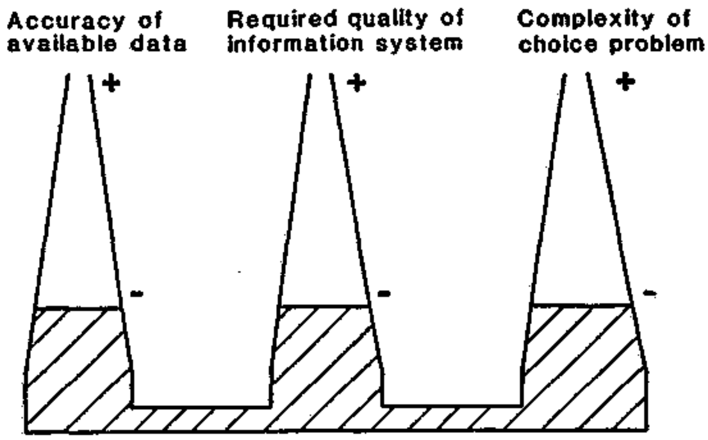
Figure 2. The demands on information systems caused by the nature of choice problems.



In this context various trade-offs in designing and using information systems, notably between accuracy, quality and complexity, have to be made.
These tradeoffs can be illustrated by means of the following "flask model", in which three flasks are connected by means of glass tubes (Figure 3). The three flasks are filled with water, while the three above mentioned conflictive issues (accuracy of data input, required quality of information system, and organization of choice problem) are measured on the necks of these flasks. With a given amount of effort (i.e. a given quantity of water in the flasks), it is easily seen from Figure 3, that a low accuracy of data will either demand a high quality of the information system or will otherwise lead to a less organized choice situation. The aim of designing a good information system is now to enhance the efficiency of data use and the effectiveness

of policy choices, based on a well-structured transformation of data into manageable policy information (by using inter alia man-machine interactions, knowledge-based systems, connecting networks, decision support systems, and so forth).

Figure 3. Tradeoffs among three items in a choice problem



A systematic and coherent insight into the complex pattern and evolution of a spatial system requires the design of an up-to-date, accessible and comprehensive spatial information system. Information systems for urban and regional planning should contain structured data on real-world development patterns, their properties (stability, for example), and their mutual links. Frequently, however, information systems as a decision aid in urban and regional development planning have too often been neglected. Therefore, much more attention needs to be paid to the design and development of information systems reflecting socio-economic processes so as to arrive at a better representation of spatial systems and a better adaptation to the needs of urban and regional planners (Blumenthal 1969; Borgers and Timmermans, 1989).

Information systems have often been designed for specific purposes; transportation data for transportation policy, housing data for housing market policy, and so on. Clearly, there are various rational (institutional and technical) reasons why integration of information systems is hard to achieve in the current planning practice. On the other hand, a lack of integration means an enormous waste of effort. It would already be a significant step forward if national or regional Bureaux of Statistics were authorized to provide uniform rules for data collection and standard classifications for economic activities, even if it would concern information systems beyond the responsibility of these national and regional bureaux. Experience in technical and medical sciences have demonstrated the power of uniform rules and classifications and there is no logical reason that would prevent the design of a standard frame of reference for the design of spatially-oriented information systems. This would also increase the polyvalence of such systems.

The popularity of spatial information systems is indeed to a large extent due to their polyvalence. They are able to include a variety of different information for a diversity of purposes, in principle associated with a multi-media system. This make GIS an instruments par excellence for spatial planning in a broad context. Clearly, in this initial stage of development of such systems, a lot of incoherence, overlap, redundance and confusion is present, which is a usual feature of the introduction of a set of competitive products. Thus the polyvalent character of modern spatial information systems is a major strength, but at the same time a risk which might hamper a flexible adoption in a planning environment.

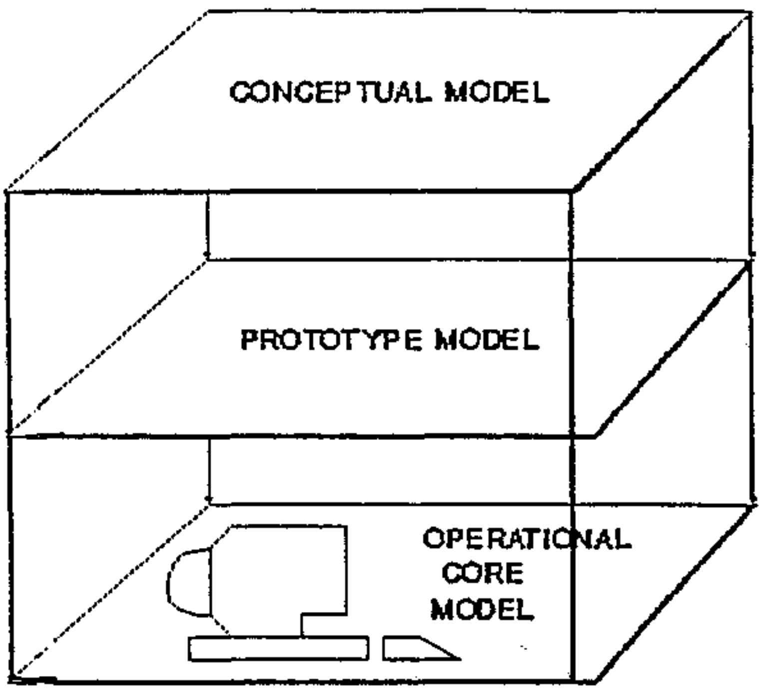
The previous observations lead to intriguing design problems. Following Hafkamp (1987) we make here a distinction between three different levels of designing an integrated system model, based on the so-called triple-layer principle.

A triple layer approach provides a set of systematic design principles for integrated systems modelling and policy analysis by making a distinction between three analytical levels:

- conceptual reflection
- prototype experimentation
- operational software development

At the conceptual level the main components of the spatial system are identified in general terms, taking into consideration the interlinks as well as the external driving forces. At this reflective level variables are not yet necessarily included as quantified units.
Next, at the level of prototype experiments a first (usually simplified) model structure is designed, which contains the key variables of the spatial system in such a way that its properties can be analyzed by means of simple simulation experiments.
Finally, the level of operational software refers to the integration of all data sources, information systems and calibrated models as ingredients for an applicable information systems model for strategic policy analysis.
The previous considerations can in a simplified way be illustrated by means of the following triple - layer figure (see Figure 4). The three steps may also serve as a communication process between expert and policy-makers. It ensures an (inter)active involvement of two parties, not only regarding routine problems but also regarding strategic choice problems in case of structural changes.

Figure 4. A triple-layer model design structure

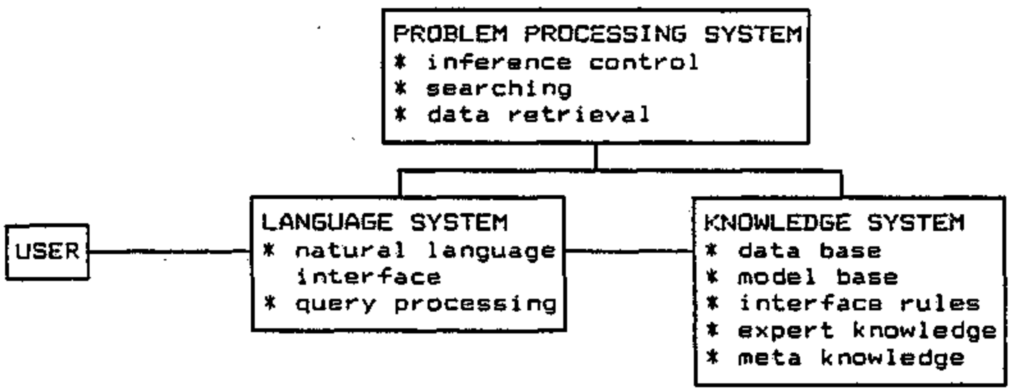


In our area of political, social and economic restructuring and technological progress, cities and regions are increasingly facing structural changes which have many drastic impacts, amongst others on the urban housing market, the urban transport system etc. In most cases, an integrated view on such developments is missing because of lack of data, inappropriate information systems or partial modelling efforts. The lack of such tools also precludes a pro-active and strategic urban planning, which would be necessary in order to cope with the above mentioned changes. This holds for urban and regional planning in general, but also for land use planning and traffic management/transportation planning.

It is essential to integrate the evaluation software with the monitoring and modelling instruments into tailor-made decision support models or expert systems. In the last few years there has been a growing interest in the use of computers in urban planning agencies. Technological developments in recent years have made it increasingly easy for planning practitioners and policymakers to get access to computers. They are becoming smaller, cheaper, easier to work with and, therefore, much more "user friendly". These developments have been re-inforced by software design, especially in the field of expert systems, which has identified greater computer usability as the key to more effective use.

An expert system is defined here as a computerized system which utilizes knowledge about a particular application area to help decision - makers solve ill-structured problems. As such, expert systems can be considered as a subset of conventional decision support systems. This subset is characterized by the fact that it concerns knowledge-based systems (see Leary, 1987, and Sagalowicz, 1984).
With the present concentration in urban planning on procedures for management, it is obvious that a strategic information systems technology for evaluation modelling not only has to cope with "hard" numerical data, but also with "soft" procedural information. In the context of "procedural" information management, expert systems promise to be a major advancement. They tend to be aimed at the organization and management of knowledge and they specifically focus on features that make them easy to use by "noncomputer" people (i.e.,non experts) in an interactive mode (cf. Freksa, 1982)
Generally, the expert systems to be developed will include the following components: a knowledge system storing knowledge about the problem domain, a language system interacting with the users, and a problem processing system directing the problem-solving processes. The integration of these three systems is also denoted as a knowledge-based system. This is summarized below in Figure 5.

Figure 5. A knowledge based system



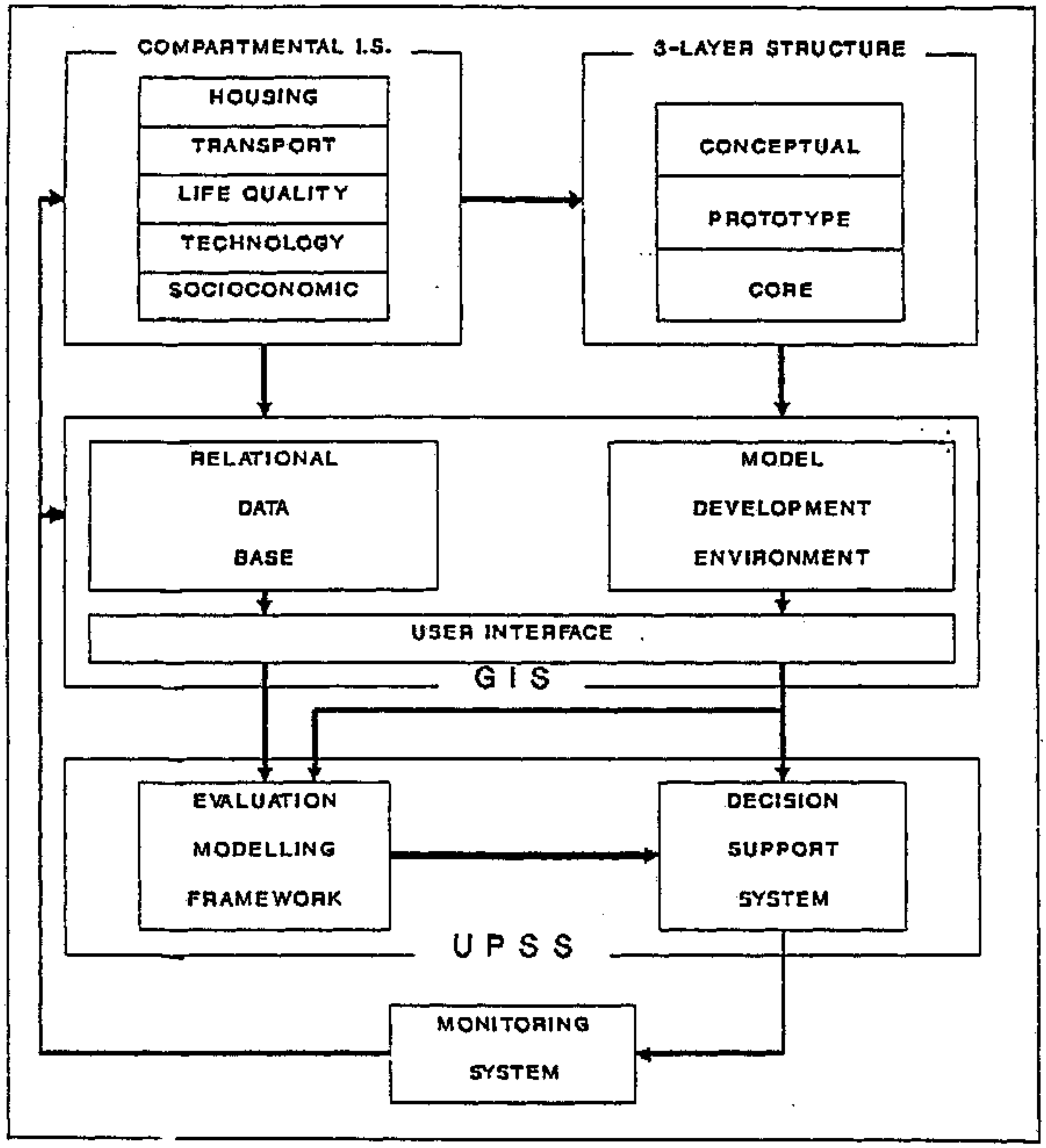
An integration of all previous elements and remarks leads to the information systems model sketched in figure 6, which contains in a systematic way all steps.

4. SPATIAL INFORMATION SYSTEMS AND REGIONAL MODELLING

Frequently, information systems for regional planning have been developed in close connection with multiregional models. Multi-regional models -as an extension of traditional econometric modeling- aim at providing consistent and coherent information on a complex spatial world, so as to identify the main driving forces and the mechanism of a complicated multiregional system (see also Issaev et al., 1982). The aim of coherence and consistency will, in general, lead to a rejection of economic models that do not take into account the openness of a region. Thus, without a consideration of interregional and national-regional links, there is no consistency guarantee for the spatial system as a whole. Usually, there are various kinds of direct and indirect cross-regional linkages caused by spatio-temporal feedback and contiguity effects, so that regional developments may have a nation-wide effect. National of even international developments may also exert significant impacts on a spatial system; this is especially important because such developments may affect the competitive power of regions in a spatial system. For instance, a general national innovation policy may favor especially areas with large agglomerations. The diversity in an open spatial economic system requires coordination of planning activities on the national and regional level, leading to the necessity of using multiregional economic models in attempts to include regional profiles in national-regional development planning.

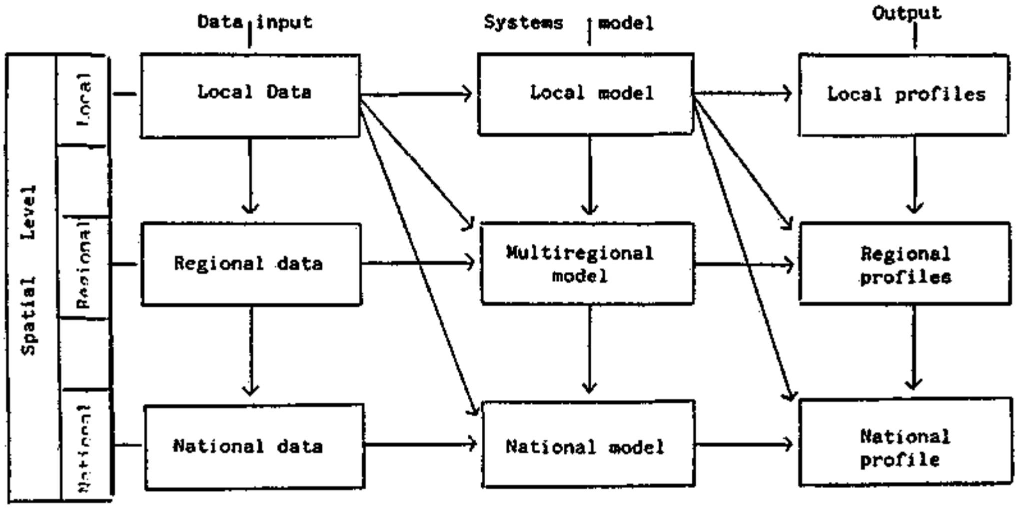
Let us now take a multiregional planning model focusing on one specific problem area (i.e., one specific profile) or on an integrated regional development pattern (including multiple profiles). Then we may assume a general systems framework for a multi-level information system (see Figure 7). This framework includes the input, throughput and output of a planning model for a spatial system subdivided into cities and regions. The right-hand side of Figure 7 reflects the expected results in terms of values of objectives, goal variables, and other relevant endogenous variables. In fact, two main questions may be studied by means of Figure 7.
- What is the optimum use of a given data input ?
- What is the optimum data input of the information system for a given set of uses?
It is clear that the second question is the dual to the first (primal) question. It should also be noted that the versatility for local data is much higher than for regional or national data, since they can be used to build 3 types of systems models and to assess 3 different types of profiles.

Figure 6. An information systems model.



Furthermore, the output of this information system also displays some interesting features. Local profiles can only be obtained by means of local data and a local model, whereas a national profile can be assessed in many ways, according to the graphs represented in Figure 7; for instance, from local data via a multiregional model to a national profile. All such combinations of ways of composing the relevant profiles are certainly worth an in-depth analysis of specific real-world planning problems, based on cost-efficiency principles. It should be noted, that not all data is necessarily observable at the most disaggregate (local) scale. This Figure 7 includes essentially the choice of an optimal trajectory for attaining a desired output, given a set of constrains on available data.

Figure 7. Structure of a multi-urban multi-region information system.



5. EPILOGUE

The previous notions have shown that the explosion of available information in combination with the modern computer hardware and software facilities provide a great deal of possibilities for coupling different information systems. Nevertheless, the actual performance of informatics in planning is often not very impressive. In this respect, urban and regional planning agencies may learn extremely meaningful lessons from multi-plant and multi-region corporate organizations, which in general, have been more able to solve the organizational problems of dealing with enormous diversified databases. In this regard, the organizational aspects of internal communication within planning agencies deserve much more attention, especially during the implementation stage.
Furthermore, it is also clear that further progress has to be made in building up new knowledge and skills in statistics, nummerical analysis, quantitative geography and evaluation methods in order to develop effective tools and procedures for GIS applications in planning agencies. The major challenge in the next years will be not expand our toolbox, but to ensure consistency in the use of models and GIS.

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