A SPATIAL DECISION SUPPORT SYSTEM FOR LOCATIONAL PLANNING: DESIGN, IMPLEMENTATION AND OPERATION

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ABSTRACT

In addition to their archival and display functions, spatial information systems have often incorporated an analytical component. Often, this capability has not provided decision-makers with the degree of modelling flexibility and support that they require. Spatial decision support systems are designed to assist decision-making by fully integrating analytical, display and retrieval capabilities; in this paper we describe the development of such a system for complex locational planning problems.

INTRODUCTION

Spatial Decision Support Systems (SDSS) are designed to provide decision-makers with a flexible and responsive problem-solving tool. In this research, an SDSS generator (Sprague, 1980) is designed to help decision-makers find solutions to complex locational planning problems. These problems are combinatorially complex because one or more locations must be selected, for a set of facilities, subject to a variety of constraints. In addition, the set of constraints often cannot be represented mathematically; for example, this occurs when they are political in nature, or are poorly defined. Consequently, traditional optimizing analysis cannot be applied <u>alone</u> to derive an optimal solution. Mathematical models <u>are</u>, therefore, used as <u>part</u> of a solution process, in which a series of feasible solutions is produced and evaluated against a set of defensible decision criteria to yield an optimal solution (Densham and Rushton, 1986).

Typically, an SDSS contains a spatial information system integrated with a modelling system. More specifically, it includes a geo-referenced database and modules, to provide analytical, display and reporting capabilities. This paper describes the development of a microcomputer-based SDSS; it is organized in four major sections - design, implementation, operation, and prospects.

DESIGN

<u>SDSS and Decision-Making</u>

An SDSS integrates analytical techniques with the expertise of decision-makers, placing the emphasis of the approach on making effective decisions (Keen and Scott-Morton, 1978; Alter, 1980). Figure 1 gives a schematic representation of the components of a microcomputer-based SDSS generator for spatial analysis (Armstrong, Densham and Rushton, 1986). It is designed to support a decision process that redefines the concept of optimality used in analysis. Keen (1977) uses Simon's three-stage model of decision-making (intelligence, design and choice) to show that traditional optimizing analysis emphasizes the choice stage, because it focuses on the optimal nature of the solution. Consequently, in traditional analyses, optimality has been defined as a characteristic of the solution. A contrasting approach to decision-making is to generate and investigate alternative solutions (Hopkins, 1984), emphasizing the stages of intelligence and design in the analysis. In this approach optimality becomes a characteristic of the whole decision process, encompassing all aspects of the problem, including those that cannot be represented in the objective function. It is this latter concept of optimality that underlies the SDSS decision process.

As Keen (1977) notes, this form of solution procedure is generally iterative. Each alternative is presented to the system user as formatted reports, maps and graphs created by the reporting and graphics modules. The alternatives are then evaluated by decision-makers, using their expert knowledge, against a set of criteria consisting of those initially thought to be important, and those not previously considered that are "uncovered" while examining alternatives. Decision-makers can accept an alternative as a satisfactory final solution or they can attempt to improve the solution by using feedback loops to modify the parameters of a model, or to specify a new one. Thus, using their understanding of the problem, decision-makers produce solutions that are optimal with respect to the dimensions and aspects that they consider to be important.

Database Requirements of Spatial Analysis

Spatial analysts use many modelling techniques. Among their repertoire is location-allocation modelling, which enables an analyst to locate one or more facilities, and to allocate demand to each facility, by optimizing the value of an objective function. This technique uses locational, topological, and thematic data which, in concert, provide the capability to capture a rich representation of the geography of a given area. Analysts require a general spatial data structure that can store and manipulate these data at a variety of spatial scales and degrees of attribute resolution (Anderson, 1978; Elmes and Harris, 1986). To support analyses, this data structure should enable specification and analysis of shapes, distances and directions, and must make comprehensive display of the data possible. Also, the data structure must easily accommodate variability in topological dimension and precision. Finally, thematic data are generally recorded in both a chronological and a categorical manner. Thus, in addition, the data structure should enable simple retrieval and manipulation of these data by time period, by category, and by both indices.

The basic element of a location-allocation model in discrete space is a graph, or network, consisting of a set of nodes and links. The nodes represent demand points, which are geo-referenced using an absolute or a relative coordinate system. Links depict transportation corridors between two nodes. The graph may be directed, signifying that only restricted movement along one or more links is possible. The friction of travel through space is represented by a "distance" value for each link - the unit is a measure of time or distance.

IMPLEMENTATION

The Database

There are many data models which can be considered for use in an SDSS; these include the rectangular, network, hierarchical, relational and extended network models. The extended network model (Bonczek, Holsapple and Whinston, 1976) has been selected because it will efficiently support the set of general capabilities described above. Also, Bonczek, Holsapple and Whinston (1981) have shown that the extended network model is a good foundation for general Decision Support Systems (DSS). The system set provides a powerful construct for directly accessing data in various locations in a database. This reduces both software development time and access times for data retrieval, because data can be accessed directly rather than by traversing intermediate records. It also enables the designer to produce a database that appears to be very close to the user-view of the data structure, yielding both flexibility and ease of use.

The database has been produced using Microsoft Pascal (Version 3.31) and MDBS Incorporated's MDBS III on an IBM PC/XT and a Leading Edge Model D. Figure 2 shows the logical structure of the implemented database, and illustrates the tripartite classification of data. This equates locational data with point and chain spatial primitives; and topological data with attribute-bearing entities such as the node, line and cell. Similarly, thematic data are represented by attributes of the topological entities stratified in a temporal data sequence. States, cities, chains and points are each defined to be system sets.

The database must be able to represent both uni-directional and bi-directional links in the network, and must record which links fall into each category. There are two 1:N (one-to-many) relationships between points and nodes enabling a point to own chains in two different sets, which are built when the user enters a chain. These sets are used to generate the appropriate data structure for standard or directed graphs.

The relationships between the topological and locational data are designed to support many levels of spatial precision. In a location-allocation framework, for example, the scale of analysis may be intra-urban or inter-urban. Each city can own one or more points and one or more chains; consequently, a city can either have an areal extent, with a boundary comprised of chains, or it can be represented by a single point. This allows both intra-urban and inter-urban networks to be established, and analysis to be undertaken at a spatial scale commensurate with both the available data and the objectives of the analysis.

The thematic data consist of six different record types; those owned by states and cities are essentially identical except for their spatial scale - both are sorted by date and contain data on variables such as population size. The third record contains the name and type of linear features represented by chains; whereas the fourth stores the name and type of point features.

The fifth type of record is owned by the chain, and consists of four fields that contain distance and distance-related data. The first field is the Euclidean distance between the endpoints of each chain, the "from" and "to" nodes. The next field is the sum of the Euclidean distances calculated between all the points defining a chain. These two values are calculated when the user enters the chain into the database. The third field contains a distance or time value specified by the user. The final field is the fractal dimension of the chain, which could be used in conjunction with low resolution data to provide realistic graphic displays (Dutton, 1981).

A node owns one or more of the sixth type of record, which consists of data required by the location-allocation routines. Five items of data are required for each of the nodes:

1) The "set" number is the identifier for each of the multiple node records.

2) The unique node identifier.

3) The demand for the service (provided by a facility, or facilities) is aggregated over space to the proximal node on the network; it is termed the "weight" of the node (Goodchild and Noronha, 1983).

4) The fourth value shows if there is a facility at a node that cannot be relocated, constraining the location-allocation heuristic to preserve existing facilities in the solution.

5) The "candidacy" of a node describes whether or not that location is suitable for a facility.

Interfacing the Database and Analytical Modules

The analytical module contains an extended version of the PLACE suite (Goodchild and Noronha, 1983) of location-allocation programs, recoded from BASIC into Pascal; it is linked to the database using a software interface. The

BASIC version of the PLACE suite requires that data are stored in files. These variables include the node weight and candidacy, the "from" and "to" nodes of each link, and its associated distance value. The node identifiers of any fixed facilities in the network are entered interactively at run-time. In contrast, the SDSS interface between the analytical module and the database retrieves data and passes it directly to the arrays used by the location-allocation heuristic.

New features permit easier and more flexible model building than can be achieved with the PLACE suite. The "set" number, in each node record, identifies each of the multiple records linked to a node, permitting the compilation and storage of different data sets in the same database. Consequently, many different analyses can be carried out easily on the same network. The interface also enables the user to specify which of the three distance values is to be retrieved and passed to the analytical module. A corollary of the calculation of link distances by the database is that the SPA5 algorithm in the PLACE suite becomes redundant, and is discarded. The interface can produce data files for the BASIC version of the PLACE suite, maintaining backward compatibility and transportability of data sets. Finally, the interface employs a number of checks for data inconsistencies.

Graphics

The display module is coded in Microsoft FORTRAN (Version 3.31) using Lifeboat Associates' HALO graphics package (Version 2.01). An interface to the database and location-allocation modules, written in Pascal, is being refined. Its function is to pass data from the database, and the results of an analysis, to the graphics module. In concert with commands from the user interface, this module produces displays of the solutions for interpretation by the users. Maps show where facilities have been located on the network, and graphs enable the user to evaluate statistical descriptions of each solution (Schilling, McGarity and ReVelle, 1982). In addition, base maps of the study area can be produced directly from the database. Various degrees of spatial abstraction can be represented on the maps, enabling the user to overlay a "landscape" to provide a frame of reference. The routines in the graphics module are being written in a modular fashion in order to facilitate migration to the GKS and virtual device interface environment.

OPERATION

The SDSS is built from several modules, which are functionally and logically distinct, corresponding to Sprague's (1980) general framework for the development of decision support systems. This modular framework has several advantages to it; the first is that a modular system is easily produced from a synthesis of existing, often commercially available, software. In addition, such a system is easily extended. New modules can be integrated with a minimum of re-coding, and maintenance of both the individual modules and the entire system is facilitated. However, a modular system can be very hard to use if a variety of existing interfaces and command syntaxes are incorporated in one system. Consequently, the operation of this SDSS is designed to be "seamless." By this it is meant that the system will appear to function as an integrated unit under an overarching, standardized interface. This structure will make the modularity of the underlying software components transparent to the user.

PROSPECTS

The PLACE suite of programs provides an excellent stand-alone location-allocation package. The integration of the suite into the SDSS, however, provides an opportunity to exploit the capabilities of other system modules; consequently, a number of extensions are planned that will enhance the flexibility of the location-allocation module over that of the PLACE suite. The first is to let the user define "templates" that will designate which links and nodes are to be dropped from, or added to, the network for analyses. Templates will enable the user to analyze partial networks derived from the main network in the database. This capability will enable a user to study each network at varying degrees of detail; and, in concert with the various spatial scales that are supported by the database, they will be able to carry out a wide range of analyses on a given database. The second extension is to enhance the reporting capabilities of the SDSS over those of the EVAL program in the PLACE suite. This change will both increase the information presented to the user and make the reports complementary to the graphical output.

The SDSS is designed to be used by a broad spectrum of users. Consequently, ease of use is an important consideration and three expert systems will be added to the SDSS to act as local or global expert controllers. A pair of local expert controllers will oversee the operation of the modelling and the graphical and reporting modules; similarly, a rule-based user interface will act as a global expert controller for the SDSS. The graphical and reporting expert controller is being developed at present.

Many applications of cartographic expert systems perform only a subset of the tasks involved in virtual map production. Based on reasoning techniques, they also have a large overhead in terms of code and computation speed that render them inappropriate for use in a microcomputer-based SDSS. However, part of the map production process can be viewed as a problem of pattern recognition, rather than reasoning; one of matching the attributes of the data to be displayed with those of various map types.

Amongst many artificial intelligence techniques for pattern recognition are Holland Classifiers (Holland, 1975, 1986), which are based on bit-mapping techniques that are fast when compared with many AI techniques. The dichotomy between a knowledge base and inference engine is maintained when the classifier is implemented in a procedural language. The classifier uses a similarity index to determine whether or not a bit string, describing the attributes of the data, matches the string associated with a particular form of map. The use of multi-letter alphabets, rather than a binary one, make it possible to define importance classes for the attributes and carry out fuzzy matching (Leung, 1983) of the bit strings.

In the system under development, the attributes will be provided from both the user and a pre-processor in the graphics interface. The user will set the values of some attributes such as the color and type of symbolization. This can be done using global variables, with the system having a set of cartographically sound default values. The pre-processor will calculate values such as the degree of spatial abstraction, and the scale of the map, from the results of the analysis and the data in the database. The classifier will then match the attributes with the bit strings describing the various forms of map, and produce the appropriate one using the results from the analysis and the locational, topological and thematic data stored in the database.

SUMMARY

A spatial decision support system for locational planning has been implemented on an IBM PC/XT. It uses location-allocation modelling heuristics, in concert with database graphics and reporting modules, to provide the user with a tool to support an iterative solution process. The integration of global and local expert controllers is being investigated, beginning with one to oversee virtual map production.

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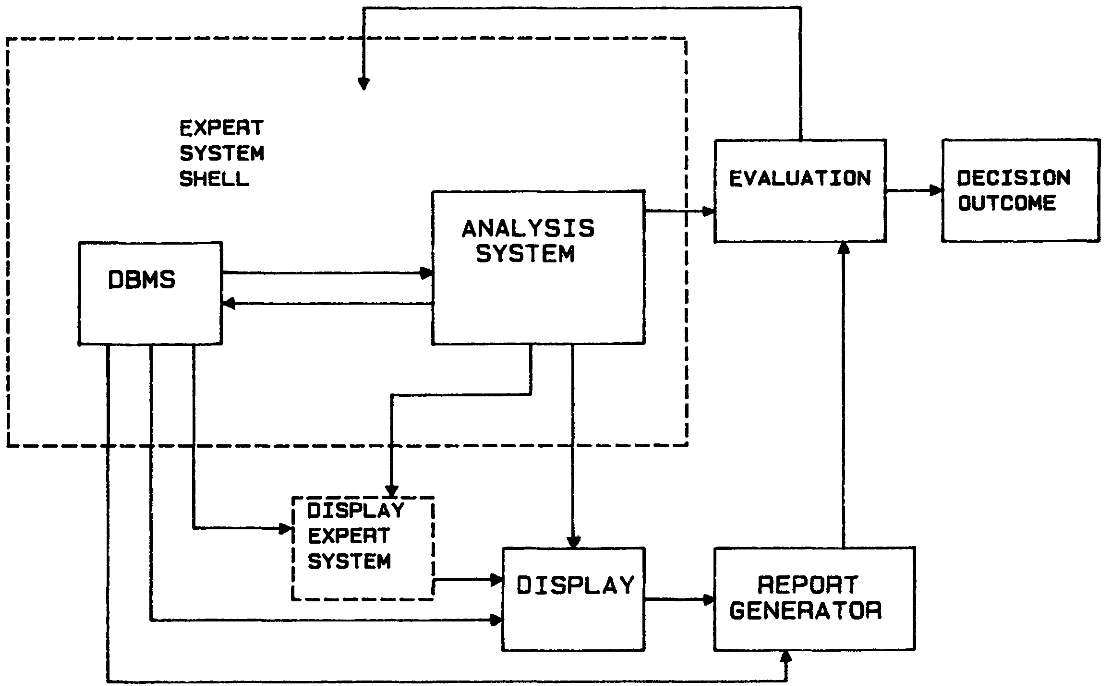
FIGURE 1: SOFTWARE COMPONENTS FOR SDSS



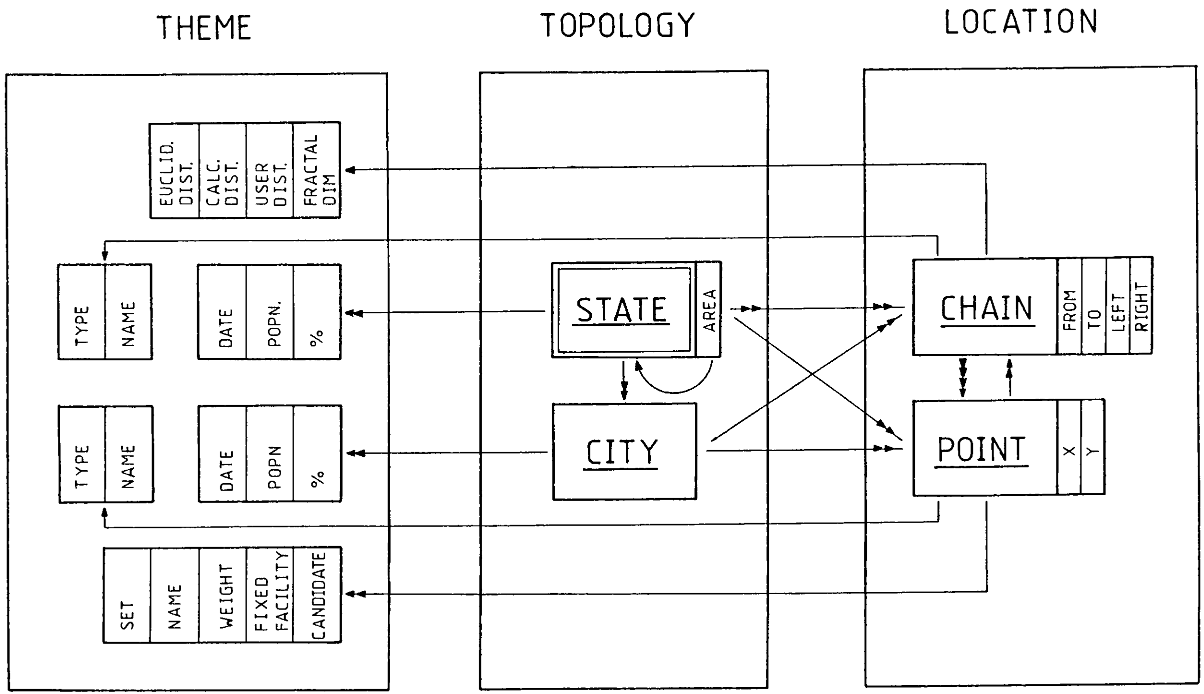


FIGURE 2: DATABASE SCHEMA