Title

Research Initiative Six: Spatial Decision Support Systems- Scientific Report for the Specialist Meeting (90-5)

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RESEARCH INITIATIVE SIX

SPATIAL DECISION SUPPORT SYSTEMS

SCIENTIFIC REPORT FOR THE SPECIALIST MEETING

14th-18th March, 1990

Santa Barbara, California

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Report 90-5

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Preface and Acknowledgements

This is a report on the first meeting of the sixth NCGIA research initiative, entitled "Spatial Decision Support Systems." This meeting, held in Santa Barbara between March 14th and 18th, 1990, was attended by representatives of the NCGIA, university faculties from Canada, the UK and the US, government agencies in Canada and the US, and representatives of Canadian and US companies. The contents of this report are compiled from the notes of the organizers, materials prepared during the meeting and the personal notes of several of the participants.

The initiative leaders wish to thank the management and staff of the Upham Hotel, Santa Barbara, for their hospitality. We also wish to thank Sandi Glendinning and Robin Chadwick of the NCGIA Office in Santa Barbara for their hard work and ready smiles.   The meeting and this report are contributions to Research Initiative #6, "Spatial Decision Support Systems", of the National Center for Geographic Information and Analysis. We acknowledge support from a grant by the National Science Foundation (SES-88-10917).

1. FRAMEWORK FOR THE INITIATIVE

1.1 Theme and Scope of the Initiative

The premise underlying Initiative 6 (I6) is that geographic information systems (GIS) provide only limited capabilities for supporting sophisticated forms of spatial analysis and decision-making. Thus, the purpose of I6 is to develop and implement a research program that will merge geographic information analysis (GIA) and GIS. It is envisaged that this merger will best occur by embedding advanced modelling techniques in a GIS with the explicit goal of providing an interactive and flexible decision-making environment. Given this purpose, the scope of the initiative encompasses aspects of GIA and GIS. Consequently, data structures, algorithms for spatial search, the application of decision theoretic techniques, the design of user interfaces, and system architectures are all considered part of the rubric of I6.

The initiative leaders decided to restrict the scope of the meeting in two ways. First, they adopted the definitions of decision support systems (DSS) developed by Geoffrion (1983) and others. These definitions focus on addressing semi-structured problems using DSS which contain one or more well-structured models used as decision aids. This approach is at odds with arguments by Cowen (1988) and others that GIS are SDSS. Second, the realm of applications to be discussed at the specialist meeting was restricted to consider marketing, retailing and location theory. This was done to enable participants to focus on a narrow set of application issues while considering a broad range of system issues.

1.2 Objectives of the Specialist Meeting

The general objective of a specialist meeting is to develop and refine a research agenda by:

- refining the dimensions of the research area, the state of current knowledge, and the important research issues within it;

- identifying and prioritizing those research issues which should be addressed by the NCGIA within the time-frame of the initiative; and

- identifying ways in which the NCGIA's efforts can be integrated with other work in the field, through joint research, exchange of personnel, mechanisms for dissemination of findings, etc.

Specific objectives for the I6 specialist meeting include (NCGIA, 1988):

- the design of GIS data structures to support decision systems;

- the development of methods for effectively structuring spatial search algorithms within a GIS framework;

- the classification of spatial search problems and the identification of gaps in current models; and

- the production and testing of prototypical user interfaces.

The initiative leaders refined these objectives and developed a potential research agenda (Densham and Goodchild, 1989) for the initiative which was presented at the GIS/LIS '89 meetings in Orlando, Florida.

2. PARTICIPANTS

2.1 External Participants

The organizers sought to bring together a wide range of people from academia and the public and private sectors. Individuals were approached who have been developing spatial decision support systems (SDSS) for both research and commercial purposes; who have expertise in marketing, retailing and locational problems; who have been working with or are mandated with solving ill-defined spatial problems; and who have experience with how other disciplines approach ill-defined problems.

Fourteen of the specialist meeting participants are affiliated with universities in four countries (Canada, India, UK, USA). One of the participants works for a Canadian public sector agency and nine other participants work for six private corporations in Canada and the US. Some of the people who were invited to the meeting were unable to attend. Among these, John Beaumont (University of Stirling) sent us a position paper (see Appendix C).

2.2 NCGIA Participants

A total of fifteen NCGIA faculty and students were invited to participate in the meeting. Five faculty and one graduate student attended from NCGIA Buffalo; one faculty member and one graduate student from NCGIA Maine and seven faculty members from NCGIA Santa Barbara also participated. These participants represented departments of geography, computer science, industrial engineering and survey engineering. In addition, a number of faculty and graduate students from the University of California at Santa Barbara attended the specialist meeting on an informal basis.

3. MEETING FORMAT

3.1 Preparation

Preparations for the specialist meeting began in July of 1989. Paul Densham and Michael Goodchild developed a research agenda for SDSS which was presented at the GIS/LIS '89 meeting in Orlando, Florida, during November 1989. The authors received comments and suggestions from a number of people who expressed interest in the initiative.

Participants were asked to prepare for the meeting by reading four papers they were sent in January, 1990 (Beaumont, 1988; Densham and Goodchild, 1989; Densham and Rushton, 1988; Goodchild, 1989). They were also asked to write a position paper, of one to two pages in length.

In these papers participants outlined SDSS from their perspective and identified research areas they saw as important. Position papers received by the organizers before the 20th February, 1990, were mailed to participants for them to read.

3.2 Working Group Formats

Participants were asked not to prepare a formal presentation for the meeting; instead, they were asked to prepare for a mixture of plenary and small working group sessions by reading papers (Appendix B contains the meeting schedule). The small working groups discussed issues identified in the plenary sessions. Each group focussed on a different issue, or set of issues, and participants chose the one they attended. The self-selection process for these groups worked very well, most of the groups had a balanced membership and none were too large or small to be ineffectual. Each group selected a spokesperson to report their discussions and findings to the larger group. To help present their results, participants had access to DOS and Macintosh word-processors and laser printers, overhead transparencies, and large sheets of paper and pens. After the first two, plenary sessions were devoted to reports from the working groups and discussion of these reports. Each plenary session was chaired by a meeting participant to help the flow of the session and to prevent the initiative leaders from unduly guiding the discussion.

4. DEVELOPING A RESEARCH AGENDA

4.1 Major Themes

The primary purpose of the specialist meeting was to discuss the impediments to widespread adoption and use of SDSS and a research agenda to ameliorate these impediments. Densham and Goodchild organized their research agenda around the four key modules of a SDSS: database management system (DBMS), analytical modelling module, graphical and tabular reporting module, and the user interface. The major research topics in this agenda are described below.

1) Database management

The DBMS of an SDSS must support cartographic display, spatial query and analytical modelling. The DBMS must integrate locational, topological and thematic data and provide the ability to construct and exploit complex spatial relations among all three data types at a variety of scales and levels of aggregation. Research topics include:

- Determining the suitability of data models, other than the relational, for use in SDSS.

- Investigating object-oriented programming techniques for developing SDSS database management systems. Because such techniques support complex spatial relations among data items in an easily extendible, modifiable and reusable manner, they appear to be well-suited to this application.

2) Analytical modelling

Solutions to analytical models often are obtained from an algorithm which, typically, consists of a series of discrete steps or "atoms." Combining atoms in different groups and sequences yields different algorithms. Once they have been disaggregated into atoms, algorithms can be described using formulae which recombine atoms in the correct sequence. Research topics include:

- Investigating the potential for developing model base management systems (MBMS) which manage atoms in much the same way that a DBMS manages data.

- Developing taxonomies of the uses to which each algorithm is put and of the atoms from which each is built.

3) Graphical display and report generation

This module provides high-resolution displays. Cartographic displays must be complemented by both general displays, such as two and three-dimensional scatter plots and graphs, and those specialized displays used to represent the output from statistical analyses and varying types of analytical models. Research topics include:

- How do we enable the SDSS user to interact graphically with the MBMS?

4) User interfaces

The user interfaces of many geoprocessing systems are modelled on those of business systems. A move towards more interactive modelling, with two-way communication taking place via a graphical display, will necessitate the development of intuitive interfaces.

- How do we support visual interactive modelling (Hurion, 1986) and enable the system user and the selected analytical models to carry out a dialogue via a graphical display? How do we let the user manipulate a model during its solution process using this graphical display?

- How should an SDSS incorporate knowledge used by expert analysts to guide the formulation of the problem, the articulation of the desired characteristics of the solution, and the design and execution of a solution process?

During the specialist meeting many of these research topics were adopted, refined, and supplemented by others. Discussion throughout the meeting centered on four major themes: the technology and implementation of SDSS, modelling and data in a SDSS, decision-making processes associated with a SDSS, and user requirements and organizational issues.

4.2 Thursday, 15th March

The first session of the day was dedicated to welcoming the participants and presenting an overview of the NCGIA and the initiative (see Appendix B). During the second session, the initiative leaders presented a set of issues which they had compiled from their own research agenda and from the position papers. Participants were asked to refine this set by adding, deleting, merging or subdividing items. Initially, there were twelve items:

1) User interfaces, cognition and reasoning
2) Architectural issues including parallelism and neural nets
3) Models
4) Decision-making processes
5) SDSS/GIS linkages
6) Data structures and data models
7) Data availability
8) Macro languages
9) Sensitivity, error and uncertainty
10) SDSS and public policy
11) Visualization and exploratory statistical analysis
12) SDSS shells and tools

Discussion during the first session resulted in the following list of topics and sub-topics:

1) User interfaces, cognition and reasoning
2) Architectural issues including parallelism and neural nets
3) Models and model base management systems (MBMS)
4) Decision-making processes
5) SDSS/GIS linkages
6) Data structures and data models
7) Data availability
8) Macro languages
9) Sensitivity, error and uncertainty
10) SDSS and public policy
11) Visualization and exploratory statistical analysis
12) SDSS shells and tools
13) Organizational context
14) Non-spatial evaluation (DSS vs. SDSS vs. EIS)
15) Decision theory
16) Taxonomy of decisions
17) Knowledge acquisition
18) Education
19) Reasoning model

Because this list is much larger than the first and contained some overlap, but no clear hierarchy of subjects, it was refined further. Items in parentheses are those that were added to a heading or subsumed by it.

A) User interfaces (macro languages)
B) Architectural issues (data structures, data models)
C) Models and MBMS (data availability)
D) Decision-making processes (cognition/reasoning, decision theory, reasoning model, SDSS and public policy)
E) SDSS/DSS/EIS (definitions and characteristics, taxonomy of decisions and technology)

F) Sensitivity, error and uncertainty (decision theory)
G) Visualization and multi-media
H) Organizational context
I) Knowledge acquisition

The items in this amended list were given the following names:

A) User interfaces
B) Architectural Issues
C) Models and MBMS
D) Decision-making processes
E) SDSS/DSS/EIS/taxonomies
F) Sensitivity and error
G) Visualization and multi-media
H) Organizational context
I) Knowledge acquisition

Participants were asked to rank the items because the six most important items would be the focus of the first working group meetings. A vote was held with each participant having six votes to allocate among items as they wished:

Group name		Votes	Rank
A)	User interfaces	23	4
B)	Architectural Issues	17	6
C)	Models and MBMS	34	1
D)	Decision-making processes	33	2
E)	SDSS/DSS/EIS/taxonomies	21	
F)	Sensitivity and error	18	5
G)	Visualization and multi-media	15	
H)	Organizational context	26	3
I)	Knowledge acquisition		7

Because of their popularity, two working groups were held on items C and D, one in each session. The first set of working groups met during two sessions as follows:

1) Thursday 1:30 - 3:15 pm

C1 Models and MBMS
D1 Decision-making processes
E SDSS/DSS/EIS/taxonomies
H Organizational context

2) Thursday 3:30 - 5:00 pm

A User interfaces
C2 Models and MBMS
D2 Decision-making processes

F Sensitivity and error

4.3 Friday, 16th March

4.3.1 Friday, 8:30 - 10:15 am

The first session, chaired by David Lanter, was devoted to reports from the first working group meetings.

Group C1: Models and MBMS Presented by Ricardo Moreno and Paul Hendriks

The point of departure for this working group was to discuss what kinds of models might be of relevance when designing a SDSS. The group noted that a lot of geographical models currently are not used in applications but, paradoxically, that many of these well-structured models could be used as building blocks to address ill-structured problems. A SDSS should support the search for structure in a problem and enable users to employ models to search for a solution.

Three different types of models were identified which have differing levels of relevance for SDSS:

1) Algorithmic Models These are well-defined such as location-allocation models.

2) Heuristically-defined Models The user begins with a loosely-defined model that is refined through successive analyses and evaluations of results. The group noted that this is really a method of developing models rather than a specific class of models.

3) Data manipulation Models In many applications data must be manipulated by a variety of simple spatial models. Data often must be aggregated over some spatial partitioning, for example, and the results from one model often must be restructured before they can be input to a second model.

A variety of models from these three classes might be included in a SDSS. These models range through exploratory data analysis, heuristics, simulation and evaluation to decision theory.

The way in which models might be incorporated in a SDSS was considered by the working group. One approach to incorporating models is to develop a model base management system by disaggregating models into atoms which are linked together to form a tree. An example used by the group was the definition of water quality. This definition, or concept, would form the highest level of the tree of atoms. To decide what defines this concept, a number of atoms would be linked together to form molecules. The atoms in the molecules would be the different branches of the tree. As one moves further down each branch, the atoms become more explicit and less conceptual. The decision-maker picks those elements from the tree that are most relevant for their particular situation, "pruning" the branches of the tree at the relevant level. The pruned tree indicates how the individual atoms are linked together to implement one or more models.

The working group next considered the three levels of technology and the five roles in Sprague's (1980) framework for DSS. The three levels of technology range from DSS tools through a DSS generator to a specific DSS; the five functional roles associated with them are DSS toolsmith, technical supporter, DSS builder, technical intermediary and decision-maker. The lowest level of technology consists of the DSS tools. These are pieces of hardware and software which are developed by the DSS toolsmith. The DSS builder integrates and configures the DSS tools to produce a domain specific, but somewhat general purpose, DSS generator. The DSS builder refines the DSS generator to yield a specific DSS which is applied to a particular problem. The technical intermediary works with the specific DSS. The decision-maker is charged with responsibility for the decision-making process and its outcome. The five functional roles may be filled by one person or by many people.

Finally, the group discussed embedding models in an SDSS using a tree-based MBMS and Sprague's framework. A taxonomy of atoms would be required for this purpose. The group was unsure whether such a taxonomy could be constructed.

Group D1: Decision-making processes Presented by Stewart Fotheringham

The first question addressed by this group was what are the reasons for using a SDSS for decision-making? In all, six reasons were identified. First, decision-making should be improved because the SDSS user has access to more information which can be used to develop a better solution. The flexibility and efficiency of the decision-making also should be improved, in part through increased access to analytical tools. Because the ethics and morals underlying a decision will become more explicit during analyses, it should be easier to make decisions. Finally, the use of a SDSS may result in a perception that the decision is more "reliable." The working group then considered who is the decision-maker, identifying four groups: the individual using the SDSS, some other individual, a small group, and the public. The issue of whether these different groups will require different types of information from a SDSS also was discussed.

The rest of the session was devoted to a discussion of the decision processes that might be used with a SDSS. The group identified four levels of decision processes in the use of a SDSS:

1) <u>The decision to make a decision</u> Can the attributes of a SDSS encourage people to agree to make a decision?

2) <u>The decision process of the decision-maker</u> What information should be supplied to a decision-maker? In its presentation, the group used retail location to illustrate the kinds of information that should be supplied to a decision-maker. This illustration served as the basis for a series of questions:

- As the decision-making process evolves, can SDSS handle the changes in the requirements of the end-user?

- How does one elicit information from end-users on what information they require? Is this task more readily achieved in a spatial context? (While spatial representations of information might be more meaningful than non-spatial ones, people are not used to thinking spatially.)

- If the decision-maker is not personally using the SDSS, how useful is the link between models and interactive visualization?

3) The decision process of individuals whose behavior is being analyzed Again, a series of questions were raised:

- How do people make spatial choices and how do they process spatial information?

- To what extent do people react to their perceived environment as opposed to their objective environment?

- Do aspatial choice frameworks fit a spatial choice problem?

- Can we model spatial competition and how do individuals react to changes in a system, such as a new retail outlet?

- Is consumer choice an issue in location problems? (Contrast the problem of siting a siren with that of a new store.)

The group noted that much of the information entered into a SDSS is screened and asked how much does this impede effective decision-making? This issue has many implications because it affects how alternatives are defined. While for many spatial problems there are spatial alternatives, are there also alternative technologies that, in turn, affect the spatial alternatives? Garbage, for example, may be burned or buried and the spatial alternatives associated with either approach may be very different.

The working group recommended, first, that there is a need to calibrate choice models at this level of the decision process and, second, to investigate the sensitivity and context-dependency of analytical models in the SDSS.

4) Decision-making after the initial decision The extent to which this occurs depends on the finality of the decision being made, which itself depends on the type of problem being addressed.

- Does the information required and the form of the decision-making process vary with the finality of the decision?

- What will be the effects of a decision on consumer behavior? Will this depend on the number of facilities being located?

- What will be the response of competitors when a decision is revealed (what are the second round and higher order impacts of the decision)? An analogy to chess can be made, the first move (decision) will have many implications for subsequent moves and counter-moves. Can the SDSS be used to play the part of competitors and to analyze what responses they might make as counter-moves? Will an intelligent SDSS prove superior to entrepreneurial skill, much as computers have proved superior to many chess players?

Group E: SDSS/DSS/EIS/taxonomies Presented by David Mark

The group noted that, in the context of SDSS, taxonomies of decisions and decision-makers could be developed separately. The group set itself the task of identifying a set of axes which could represent salient characteristics in one or more taxonomies. These taxonomies would, hopefully, be consistent with the needs of system designers, researchers and decision-makers. Three axes were identified that relate to decision-making:

1) Whether the task is routine or encountered rarely.

2) The commitment of the decision-maker to the decision-making process or to the implications of the adopted solution, termed the decision-maker’s "stake." This axis has two elements, the degree of risk and the likelihood of payoff, and the decision-maker’s ethics and degree of responsibility.

3) The location of the problem within the space characterized by the three dimensions of space, theme and time.

Group H: Organizational context Presented by Martin Clarke

This group discussed the links between consumers, corporations and academics. Several questions were raised including: should SDSS have different interfaces for consumers and academics, and is technology driving the applications or are applications driving the technology? The group perceived the organizational context of SDSS as a matrix with three-dimensions: the type of organization using an SDSS; the functions required of the SDSS; and the users of the system. The types of organizations which could use SDSS widely include public agencies, transportation, banking, retailing and insurance. Within these organizations the users of an SDSS would include technical specialists, clerks, administrators, line managers, planners and executives. The functions these users will require of their SDSS include data retrieval, data query, mapping, decision making and corporate planning.

The group felt that there should be different levels in an SDSS, each appropriate for a different type of user within the organization. This was recommended because the group saw the process of problem definition as one of negotiation and because the criteria for evaluation of a solution are highly complex and often qualitative in nature. Legal requirements, for example, may dictate that some solutions are unacceptable, despite their robustness in analyses; examples occur in banking (redlining), insurance (flood plains) and political redistricting.

The group noted that one decision-making process that has been used successfully by vendors and their clients consists of seven steps:

1) Defining the problem.

2) Identifying goals and objectives and determining measures for them (quantify reality).

3) Selecting models to derive measures.

4) Collecting data which is used to generate alternative solutions with the models.

5) Assessing preferences for the alternatives and choosing one.

6) Sensitivity analysis.

7) Documenting the decision-making process by displaying the results and formalizing a script, or audit trail, of how the decision was reached.

Group A: User interfaces Presented by Geoff Wright

The group assumed that a SDSS is a DSS with a GIS, or spatial database component and addressed the question of what are the differences and similarities in interfaces among GIS, DSS and SDSS. It concluded that GIS interfaces need only to provide access to data and data operations while SDSS interfaces, in addition, must be able to display, manage and interact with the solution space. Several specific observations were made about the development of interfaces for SDSS:

1) A rich environment for interface design is available because the results of analysis and alternative problem solutions can be explored using a variety of spatial analogues.

2) Users of an SDSS will want to interact with the models and data in the system to change model formulations and parameter values. The ability to interact with models and data using a graphical representation provides the decision-maker with a more natural mode of interaction.

3) The spatial orientation of SDSS opens up opportunities for the extended use of other advanced multimedia technologies such as interactive video, animation, color (beyond 8-bit), and other future technologies. Although this also is true of DSS, there is a more natural, compelling and established need for this support within spatial decision-making.

The group felt that, currently, interfaces are not hindering the development of SDSS. Some group members recommended, however, that "visualization and exploratory data analysis" should be returned to the list of discussion topics.

Group C2: Models and MBMS Presented by Dale Honeycutt

Discussion during the first part of the meeting revolved around more conceptual issues:

- Modelling is as much an art as it is a science. When the modeller applies a model they typically must fill in gaps in the data, deal with imperfect data, and circumvent resource constraints.

- Modelling is a learning process. Through models we characterize the data and the problem and educate the decision-maker.

The group developed a causal classification of models:

1) Exploration and characterization models:

Group A:

- Calibration
- "Feel" the data
- EDA (Exploratory data analysis)
- Data Reduction

Group B:

- Preference elicitation

2) Generation of alternatives

3) Evaluation of alternatives

The second portion of the meeting was dedicated to identifying researchable topics. The following areas were discussed:

1) Given technological advances, what sorts of models are likely to be developed and/or applied in the future? One suggestion was that there exists a large body of small area spatial forecasting models that could be applied.

2) What sorts of models exist on the periphery of SDSS. A model that predicted radiation contamination, for example, could be used in a routing analysis. Knowledge about these models would help to integrate SDSS in vertical markets.

3) What sorts of materials would an analyst like to have in their toolkit? A computer library of routines that worked on certain data structures was suggested as well as annotated bibliographies.

4) A series of case studies would be helpful for educating both decision-makers and analysts. A series of unambiguous problems could be formulated for which "experts" would describe their modelling approaches and concerns.

Group D2: Decision-making processes

This group did not meet because those wishing to discuss this topic attended the meeting during first session.

Group F: Sensitivity and error Presented by Lewis Hopkins

This group discussed a wide range of issues that fall into five categories:

1) Interpretation of results in decision spaces One interpretation of error is to consider the effect it has on the robustness of decisions. Decision-makers wish to know under what conditions their decisions become inappropriate. Thus, decision-makers must determine whether the differences between alternative solutions are real and justify adopting a new course of action, with its associated costs. The need to examine carefully any perceived differences between alternatives arises from errors in input data, model specification, model validity, algorithms, or preference elicitation. If the robustness of decisions are to be understood, the effectiveness of the SDSS must be evaluated. Observable differences in the cost of decision-making alone cannot be used for this purpose because, in the absence of other criteria, rapidly-made decisions will always be preferred to longer deliberations. An operational measure of effectiveness is the level of confidence a decision-maker places in a given decision. A SDSS may be valued if it persuades the decision-maker that a good decision is being made, even if the adopted outcome is poor.

2) Uncertainty and problem formulation The group felt that uncertainty should be an integral part of the decision process to be addressed directly, rather than minimized by a strategy of attempting to reduce error. Instead of using "better" models that contain less error, some problems are best reformulated to identify robust strategies that maximize flexibility. School redistricting was cited as an example. Because small-area population forecasts are notoriously difficult to make, trying to improve forecasting methods or deriving confidence limits may appear, falsely, to remove uncertainty.

3) Error in input data Errors in input data can be addressed by intelligent formulation of models. In locating cellular telephone transmission towers, for example, USGS data with known error-limits is available for locations and heights. Building in redundant coverage of towers will ensure that errors in the USGS data for the locations and heights of the towers will not affect the performance of the system.

4) Sensitivity analysis Visualization of the sensitivity of attributes to changes in geographic or decision space will enhance the process of sensitivity analysis. For example, surface representations of geographic and decision space could be used to depict the change in an attribute, z, with respect to x and y. The features of these surfaces would help decision-makers to recognize the robustness of a solution and to identify feasible or good modifications. Thus, moving one location in a set would result in the surfaces being adjusted to show the sensitivity of all the locations to the change.

The group suggested that a key role for modelling support will be the maintenance of feasibility and goodness with respect to the modelled attributes while the decision-maker intervenes and concentrates on particular decision variables.

5) Visualization Another use for visualization would be to highlight the differences in the quality of the decision support being provided by the SDSS. Varying the intensity of the background color, for example, could be used to indicate the quality of the data and models

being used.

4.3.2 Friday, 10:30 - 12:00 am

During the second session, chaired by Gerard Rushton, participants formulated the topics of the second set of working groups. Participants were asked to differentiate between general research areas in SDSS and those research areas that are key for the development of SDSS. Gerard Rushton presented a typology of research areas developed from the reports presented in the first session of the day. The typology consisted of four elements:

A) Decision-making processes:

- how do we increase the quality of problem formulation, the process of structuration?
- what exploratory spatial and data analysis tools do we make available to the decision-maker?

B) Modelling and data:

- how do we design and implement model base management systems?

C) Technology and implementation:

- how do we provide the decision-maker with the ability to move between the decision space and geographic space?

D) User requirements and organizational issues:

- how should we develop taxonomies to assist the designers of SDSS?

After discussion, two additional elements were thought to be necessary. First, spatial choice modelling was added to the modelling category. Second, the question was raised of how we add theory to a SDSS that decision-makers can draw upon in solving problems. Further discussion resulted in a modified set of categories that were used as discussion guidelines for the second set of working groups:

A) Decision-making processes:

- how do we increase the quality of problem formulation, the process of structuration?
- what exploratory spatial and data analysis tools do we make available to the decision-maker and how are they visualized?
- what are the effects of moving from geographic space to the decision space and *vice versa*?

B) Modelling and data:

- how do we design and implement model base management systems?

- which model developments are useful to the development of SDSS and which are crucial?

C) Technology and implementation:

- how do we provide the decision-maker with the ability to move between the decision space and geographic space?

- what are the architectural issues to be addressed in the implementation of SDSS?

- what is the relationship between GIS and analytical modules in the context of SDSS development?

D) User requirements and organizational issues:

- how should we develop taxonomies to assist the designers of SDSS and of what should these taxonomies consist?

4.3.3 Friday, 2:00 - 2:30 pm

The first afternoon session was devoted to software demonstrations. Jacek Malczewski showed the Dynamic Interactive Network Analysis System (DINAS), developed at IIASA, and Martin Clarke demonstrated a system developed for Toyota, U.K.

4.3.4 Friday, 3:00 - 5:00 pm

During the final session on Friday, the second set of working groups met.

4.4 Saturday, 17th March

4.4.1 Saturday, 8:30 - 10:15 am

The first session on Saturday, chaired by Richard Church, was devoted to reports from the second set of working group meetings.

Group A: Decision-making processes Presented by Lewis Hopkins

This working group identified three topical areas for research which are mutually reinforcing.

- What strategies are most appropriate for applying well-defined models and tools to exploratory analysis for ill-structured problems, to resolve (rather than solve) them?

- How should transformations occur between the decision space, the model space, geographic space and objective space? Some representations will be better for different kinds of problems.

- What system architectures can best support a SDSS that acquires knowledge from a decision-maker?

These areas are linked because experiments to test hypotheses about the first will rely on concepts from the second and require prototypical system implementations from the third area.

Group B: Modelling and data Presented by Piotr Jankowski

This group felt that MBMS and models are critical to the development of SDSS. A number of research areas were identified:

- A taxonomy of spatial models relevant for SDSS.

- A taxonomy of the atomic elements common to spatial models.

- Developing a knowledge base on the sensitivity of spatial models to parameter changes, data quality, calibration procedures, data aggregation, parameter stability over time and space, and data availability.

- Developing data models for use in SDSS.

- Issues related to model chaining, or linking, in MBMS including error propagation, the logical context of linking, and the level of data used.

- Developing flexible algorithms that can cope with changes in parameter values, for example, when they are part of a sequence of models.

- Developing faster algorithms that will permit the decision-maker to interact more easily with their problem.

Group C: Technology and implementation Presented by Marc Armstrong

The group asked the question how can SDSS be used to empower the decision-maker? Four elements of an SDSS are crucial in this endeavor: the representation of the problem (both in the machine and to the decision-maker), the SDSS software, the hardware on which it runs, and the user interface. The group identified eight specific research areas, each of which relates to one or more of the four elements of an SDSS.

- What are the guiding principles within decision domains that inform the assemblage of analytical components in a SDSS? Research is needed to enable SDSS designers to identify, elicit and represent these principles and for decision-makers to use them. These principles will be represented as three kinds of knowledge within a SDSS: environmental knowledge, such as the geometry of the study area; structural knowledge about the situation, for example; and procedural knowledge, which normally is supplied by an expert analyst.

- What is the scope for object-oriented programming (OOP) techniques in SDSS? Research is needed to establish whether such techniques can be used for data representation, MBMS, and linkages between data and models.

- Are multiple representations necessary to support spatial decision-making? Traditionally, graphical and analytical representations have differed. A transportation link, for example, may be represented by a chain of coordinates for display or a pair of start and end nodes with a series of attributes for analyses. Consequently, research is needed into data structures that can support both cartographic display and analytical modelling.

- How does the system adapt to the user's evaluation of an analysis? The underlying assumption here is that users are in an iterative, interactive decision-making environment. What tools are needed to elicit evaluations from individuals and to respond to changes in preferences?

- How can a SDSS effectively support group decision-making and evolving decision-making processes?

- How does the decision-making context within the corporation affect the architecture of the SDSS? An organization must provide staff, data and hardware resources if it is to support an SDSS - at what levels will these resources be made available?

- How do we convey complex information to a decision-maker? The use of a SDSS implies that there are multiple criteria and constraints, alternative scenarios, and interactions between the decision space and geographic space, all of which must be represented and made accessible to the decision-maker.

- What is the value of parallel processing for supporting spatial decision-making? The assumption here is that current technology is somewhat lacking in its ability to provide responses to a decision-maker in times that are deemed acceptable for problems of realistic size. A consideration of parallel processing technology will require us to examine issues related to geometrical decomposition of problems and the temporal synchronization of problem elements, among others.

Group D: User requirements and organizational issues Presented by Bruce MacDougall
The recommendation of this group was that a taxonomy be developed that would meet the needs of academics and system designers and vendors. The taxonomy would take the form of a tree with several levels of branches:

- Decision situation This is the root of the tree and the focal point of the taxonomy.

- Routine/non-routine decision-making Is the problem repetitive or is it encountered rarely?

- Stake What is the commitment of the decision-maker to the decision-making process and to the solution that is adopted?

- Individual/multiple decision-makers Is the decision-making done by a group or an individual, is it subject to review by the public or the courts?

- Tool needs What are the tools required to address the problem?

- Tool availability Which tools exist, are they in a form that can be used in a SDSS?

The feeling of the group was that by fleshing out the tree, moving down the list above, it would be possible to determine which tools do not currently exist and are hindering the adoption and application of SDSS. This taxonomy would also highlight the similarities and differences among the decision-making undertaken in a variety of decision contexts and organizational settings. Thus, the group recommends research to identify the factors in problems and the tools that are needed to address them.

4.4.2 Saturday, 10:30 - 12:00 am

During the second session, working groups were asked to reform and carry out a number of tasks:

- To revise their research agenda in the light of other group presentations to reduce duplication and support other efforts.

- To suggest how the agenda might be tailored to fit within the constraints facing NCGIA - namely a two-year life for the initiative and resource constraints.

- To identify the highest priorities for research, given the constraints above.

- To determine what infrastructure is required to carry out the research (newsletters, publications, symposia, etc.).

- To identify potential funding sources to support the research.

- To consider the potential for industry and academic partnerships and what role they might take in the initiative.

The groups reformed, addressed these tasks, and presented their revised research agendas:

Group A: Decision-making processes Presented by Lewis Hopkins

After due consideration, the group members felt that three topical areas for research are mutually reinforcing and could not be prioritized:

- What system architectures can best support a SDSS that acquires knowledge from a decision-maker?

  A number of items will have implications for the system architecture. A system which brings to bear knowledge and models on incompletely defined problems must work with a constantly evolving shared knowledge between itself and the decision-maker. Object-oriented programming approaches appear to provide a structure that tightly links procedures and data. Human-computer interaction might be facilitated by OOP techniques because the memory structures of both human and computer would be more similar. The group recommends that a set of criteria are established for system development and used to implement some prototype systems. Because these prototype SDSS must represent and use knowledge internally, they are likely to include logic programming, or artificially intelligent, elements. Criteria also should be established and tested, using prototype systems, for these elements. Intelligent system elements will be needed in MBMS, for example, which the group recommends are developed for existing spatial search and simulation models.

- How should transformations occur between the decision space, the model space, geographic space and objective space?

  Decision spaces yielded by well-defined models and human decision-makers are incomplete when applied to ill-defined problems. In contrast, rich representations of geographic space appear to be an excellent tool for challenging biases and assumptions, and objective space is potentially a complementary representation. From the perspective of SDSS, a central issue is how to complement humans and models with representations of geographic space. While we cannot know in advance what information will expand the problem, we should be able to discover strategies that help us to learn about problem domains and decision-making behaviors that will be helpful. Thus, what should we represent? How should it be represented? What is too much at a time or per unit of time? How can we transform the current state of a model or a decision-maker into geographic space in partially systematic ways?

- What strategies are most appropriate for applying well-defined models and tools to exploratory analysis for ill-structured problems, resolving (rather than solving) them?

  We should learn more about which strategies let us use our tools effectively. One strategy is to increase the depth of investigation of one, or a very few, alternatives by repeatedly refining simulations and carrying out sensitivity analyses. This may be a good problem exploration strategy. It is the most frequently observed strategy of successful decision-makers. In contrast, one branch of the problem exploration literature suggests that the number of alternatives considered is more effective in finding a good solution. Either strategy may be used, however, to expand the definition of a problem and to counter biases. Though the conventional wisdom is that deepening the search increases the anchoring on a single alternative and broadening the search does not, there is little evidence to support this contention and some to contradict it. These two strategies may, of course, be complementary, but they require different tools, different system designs and a strategy for using them together.

Research results about these problem exploration strategies are likely, at least in part, to be domain specific although some results may be generalizable to wider domains. Spatial problems have significant advantages from an experimental design perspective, so more general results should be sought through the use of SDSS.

Group B: Modelling and data Presented by Piotr Jankowski

This group reduced its research agenda to three priority topics:

1) A taxonomy of spatial models relevant for SDSS.

2) A taxonomy of the atomic elements common to those spatial models that are relevant for SDSS.

3) Developing a knowledge base on the sensitivity of spatial models to parameter changes, data quality, calibration procedures, data aggregation, parameter stability over time and space, and data availability.

Group C: Technology and implementation Presented by Marc Armstrong

This group felt that all the elements of their original agenda should remain, but the research questions were refined and prioritized:

1) What is the scope for object-oriented programming techniques in SDSS?

This approach provides a conceptual framework for implementing SDSS. Research is needed to establish how such techniques can be used for data representation, MBMS, and linkages between data and models.

2) How does the system adapt during the decision-making process?

- How does the system adapt to the user's evaluation of an analysis?
- What tools are needed to elicit evaluations from individuals and to respond to changes in preferences?

3A) Representation:

- What kinds of multiple representations are necessary to support spatial decision-making? Traditionally, graphical and analytical representations have differed. Are additional representations necessary?
- How does OOP facilitate multiple representations?

- Are there model-specific data structures, or can more general data structures be used?

- How do we represent geographic and decision or objective space?

3B) What forms of visualization must be supported in a SDSS?

- How do we convey complex information to a decision-maker?

4A) How do we elicit, identify, represent and use knowledge in an SDSS?

- What are the kinds of knowledge needed?

- What are the guiding principles within decision domains that inform the assemblage of analytical components in a SDSS?

4B) How can we provide adequate system responsiveness?

- What is the role of parallel processing and problem decomposition for supporting spatial decision-making?

Group D: User requirements and organizational issues Presented by Bruce MacDougall
The recommendation of this group was that a taxonomy of spatial problems is developed which would consist of several levels:

- o What is the decision situation?

- o Is the problem faced routinely?

- o What is the stake of the decision-maker?

- o How many decision-makers are there?

- o What are the tools needed to address the problem?

- o Are the necessary tools available?

To produce this taxonomy the group suggested three priorities for research:

1) Case studies of the use of SDSS should be carried out including companies which repeatedly face ill-defined spatial problems. A classic example is the location of franchises by companies such as Pizza Hut. Another, timely, problem that could be studied is that of census redistricting.

2) Carrying out a literature search to identify the factors that occur in ill-defined spatial problems.

3) Evaluating the significance of a number of selected problem factors. We can determine whether the tools required to address significant factors are currently available in a form that can be used in a SDSS.

4.4.3 Saturday, 2:00 - 5:00 pm

The afternoon was devoted to a plenary session, chaired by Paul Densham, to discuss the final research agenda and to develop plans for the initiative. Participants agreed that a newsletter would be a useful mechanism for keeping everyone informed of the progress of the initiative. Bruce Ralston agreed to edit the newsletter. To make early research results available to a wider audience, participants compiled a list of future conferences that they will be likely to attend at which special sessions on this initiative could be held. A list of agencies and institutions that could be approached for research funding also was compiled.

5. PRODUCTS OF THE INITIATIVE

The primary product of the initiative is the research agenda developed at the specialist meeting. Additional items have been produced. Michael Gould and Paul Densham compiled a bibliography on SDSS and DSS which was circulated to participants of the specialist meeting. A mailing list has been compiled which will be used to circulate the initiative newsletter - edited by Bruce Ralston. In addition, a number of papers related to this initiative have been written:

Refereed Journals

Armstrong, M.P. and Densham, P.J. (1990) Database organization strategies for spatial decision support systems. **International Journal of Geographic Information Systems**. 4: 3-20.

Couclelis, H. Geographically informed planning: requirements for planning-relevant GIS. **Papers of the Regional Science Association** (under review).

Densham, P.J. and G. Rushton. Strategies for solving large location-allocation problems by heuristic methods. **Environment and Planning A** (under revision).

Conference Proceedings

Armstrong, M.P. Densham, P.J. and Bennett, D.A. (1989). Object-Oriented Locational Analysis. **Proceedings**, GIS/LIS ’89 (Orlando, FL.) pp. 717-726.

Densham, P.J. and Goodchild, M.F. (1989) Spatial decision support systems: a research agenda. **Proceedings**, GIS/LIS ’89 (Orlando, FL.) pp. 707-716.

Dissertations

Willer, D.J. (1990). **A Spatial Decision Support System for Bank Branch Location**. Unpublished Master’s Project, Department of Geography, State University of New York at Buffalo, Buffalo, NY 14261

6. SUMMARY

During the course of the specialist meeting, participants developed a research agenda for SDSS which centers around four major themes:

1) Decision-making processes with SDSS:

- What system architectures can best support a SDSS that acquires knowledge from a decision-maker?
- How should transformations occur between exploratory resolution spaces for ill-defined problems?
- What exploratory strategies are most appropriate for ill-structured problems?

2) Modelling and data in SDSS:

- A taxonomy of spatial models relevant for SDSS.
- A taxonomy of the atomic elements common to spatial models.
- Develop a knowledge base on the sensitivity of spatial models to a wide range of factors.

3) Technology and implementation of SDSS:

- What is the scope for object-oriented programming techniques in SDSS?
- How does the system adapt during decision-making?
- What kinds of multiple representations are necessary to support spatial decision-making?
- What forms of visualization must be supported in a SDSS?
- How do we elicit, identify, represent and use knowledge in an SDSS?
- How can we provide "adequate" system responsiveness?

4) User requirements and organizational issues for SDSS:

- Case studies of the use of SDSS

- A literature search to identify factors in ill-defined spatial problems and the tools required to solve them.

- Evaluate the significance of a number of selected problem factors - are tools available for them?

One of the largest benefits of the specialist meeting is that a cadre of researchers have discussed the impediments to the widespread adoption of SDSS and have developed a common understanding of the magnitude and relative importance of these impediments. This shared understanding provides a starting point for research under the aegis of the initiative. Many of the participants were working on parts of this agenda before the specialist meeting, others have indicated that they will adopt elements of it in their own research. A newsletter is planned to help these researchers coordinate their work and to be informed of what others are doing.

It is important to note that the formal termination of the initiative (currently planned for the spring of 1992) will not signal the end of research on SDSS. Rather, the research carried out during the life-span of the initiative will further refine the research agenda and make it accessible to a wider research community.

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Appendix A. List of Participants

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Appendix B. Meeting Schedule

Wednesday March 14th

Arrival, hotel check-in

7:00pm Reception (wine and cheese)

Thursday March 15th

8:30am Welcome, introduction (David Simonett, co-Director, NCGIA)

Overview of NCGIA activities and research intiatives (Mike Goodchild, co-director, NCGIA)

Overview of Initiative 6 (Paul Densham, NCGIA Buffalo) and meeting format

10:15am Coffee

10:30am Formulation of topics for the first set of working groups
Chair: Michael Goodchild

12:00pm Lunch

1:30pm First working groups meet, session 1

3:00pm Afternoon break

3:15pm First working groups meet, session 2

5:00pm Break for the day

Friday March 16th

8:30am Plenary session, presentations by the first working groups and discussion
Chair: David Lanter

10:15 am Coffee

10:30 am Formulation of topics for the second set of working groups
Chair: Gerard Rushton

12:00 pm Lunch

1:30 pm Demonstrations of software

2:30 pm Afternoon break

3:00 pm Second working group sessions

5:00 pm Break for the day

Saturday March 17th

8:30 am Plenary session, presentations by the second working groups and discussion
Chair: Richard Church

10:15 am Coffee

10:30 am Working groups to finalize the research agenda and group presentations
Chair: Michael Goodchild

12:00 pm Lunch

1:30 pm Plenary session to discuss plans for the initiative
Chair: Paul Densham

3:00 pm Afternoon break

3:15 pm Plenary session to discuss plans for the initiative
Chair: Paul Densham

5:00 pm Break for the day

7:00 pm Dinner at Alex's Cantina, 633 State St.

Sunday March 18th

Informal discussions, departure

Appendix C. Position Papers

Luc Anselin, Integrated Multiregional Socio-Economic Models and Spatial Decision Support Systems.

Marc Armstrong, Research Directions for Spatial Decision Support Systems.

Rajan Batta, Developing a Decision Support System for Locating Emergency Facilities in a Congested Environment.

Michael Batty, Decision Support for Land Use-Transportation Planning Based on Spatial-Allocation Models.

John Beaumont, Spatial Decision Support Systems: A Personal Agenda for a Research Initiative.

Richard Church, Spatial Decision Support Systems.

Martin Clarke, Spatial Decision Support Systems: A Case of the GIS Tail Wagging the Analytical Dog?

Donald Cooke, Spatial Decision Support Systems.

Paul Densham, Spatial Decision Support Systems: Supporting Visual Interactive Modelling.

Stewart Fotheringham, Some Random(ish) Thoughts on Spatial Decision Support Systems.

Barry Glick, Position Paper.

Michael Gould, Thoughts on the Design of User Interfaces for Spatial Decision Support Systems. Problem #1: Who is the User?

Eric Heikkila, Position Paper.

Paul Hendriks, Notes on Research Issues Concerning SDSS.

Lewis Hopkins, Spatial Decision Support Systems: Research Initiative Position Statement.

Piotr Jankowski, A Model Management Approach to Analytical Modelling in Geoprocessing Systems.

David Lanter, On the Philosophy of Geographic Decision Support Systems.

Bruce MacDougall, Position Statement for the NCGIA Specialists' Meeting: Spatial Decision Support Systems.

Giulio Maffini, Spatial Decision Support Systems: Position Paper.

Jacek Malczewski, Dynamic Interactive Network Analysis System (DINAS).

David Mark, Position Paper for the Specialist Meeting: Spatial Decision Support Systems.

Harlan Onsrud, Position Paper for the NCGIA I-6 Specialist Meeting.

Bruce Ralston, Some Talking Points on Spatial Decision Support Systems.

Peter Rogerson, Monitoring, Updating, and Sensitivity Analyses in Spatial Decision Support Systems for Demand Forecasting.

Gerard Rushton, Integrating Preference-Based, Location-Allocation and Behavioral Location Theory Methods in Decision-Support Systems for Locational Decisions.

John Tulip, Position Paper: Spatial Decision Support Systems.

Nigel Waters, More on the Research Agenda for SDSS.

Lyna Wiggins, Position Paper on Spatial Decision Support Systems.

Sidney Witiuk, Spatial Decision Support Systems: A Position Paper.

Jeff Wright, SDSS in Public-Sector Engineering.

Roger Yetzer, A Focus on Spatial Decision Support Systems.

Integrated Multiregional Socio-Economic Models and Spatial Decision Support Systems

Position Paper for the NCGIA Research Initiative on Spatial Decision Support Systems

March 14-18,1990

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Introduction and Background

The traditional tools of the regional scientist to deal with socio-economic policy issues at the macro level (e.g., demographic models, input-output models, econometric and forecasting models) lack a strong integration of three aspects of DSS: the data, the model (analysis) and the decision making process. This; is also the case in the now proliferating "canned" packages for regional impact analysis (mostly based on various ad hoc procedures to estimate a regional input-output model, see, e.g., Brucker et al., 1987). Not only is the decision context in which these models are to be used totally ignored, but the treatment of data and data base issues is rather simplistic.

Although in principle it is fairly straightforward to envisage an integrated approach to regional policy analysis (see the attached figures) and the conceptual development of this has already generated considerable discussion (e.g., Isard and Anselin, 1982; Anselin and Arias, 1983; Anselin and Madden, 1990), the problems encountered in the practical implementation of such integrated frameworks are rather formidable (e.g., Anselin and Rey, 1989). As I pointed out elsewhere (Anselin, 1990) many of the issues encountered in such integration are inherently spatial (e.g., regional aggregation and disaggregation, variable reporting zones, inter-regional flows) and the associated data manipulation is a natural area of application for a GIS (an initial application is described in Anselin et al. 1990). However, the extent to which the model integration itself and its incorporation into the decision context and decision process of policy makers needs to be part of the GIS (as a spatial DSS) is a question that remains to be resolved. I see the current NCGIA initiative as a means to make significant progress in this area of research. Following are some topics which I suggest for discussion in this context.

Research Priorities

1. A detailed taxonomy of what are the distinctive "spatial" characteristics that make an SDSS distinct from a traditional DSS.
2. A categorization of spatial analysis tools, both of those existing (e.g., spatial statistics, spatial choice modeling, spatial interaction modeling, location-allocation modeling) and of those currently lacking that are needed to tackle the "spatial" aspects of SDSS. This should result in an evaluation of the relative merits of these tools in different decision situations: micro level planning vs macro level planning; special purpose systems vs. general purpose systems, etc.
3. The development of "spatial" models of decision making for a range of different decision situations, e.g., single decision maker, multiple decision makers with common goals, conflicting interest groups, etc.. One question that needs to be addressed is the extent to which there is a need for such spatial models, rather than just applying known techniques (multiobjective programming, multiattribute utility theory, AHP, etc ...) to spatial decision situations.
4. An exploration of effective ways to make a link between a spatial data base, socio-economic models (e.g., input-output, structural econometric, forecasting, optimization), and the planning decision context. This includes dealing with issues such as error propagation, translation of model outputs to the end user (user interface), flexible combination of different aspects of the models, etc... The end result would be a prototype spatial decision support system for planning and policy analysis at the macro level.

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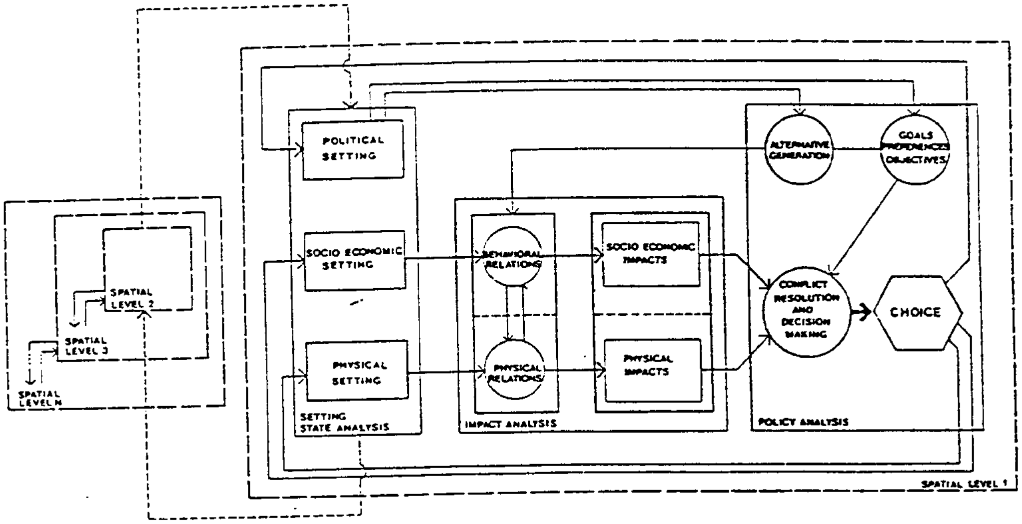
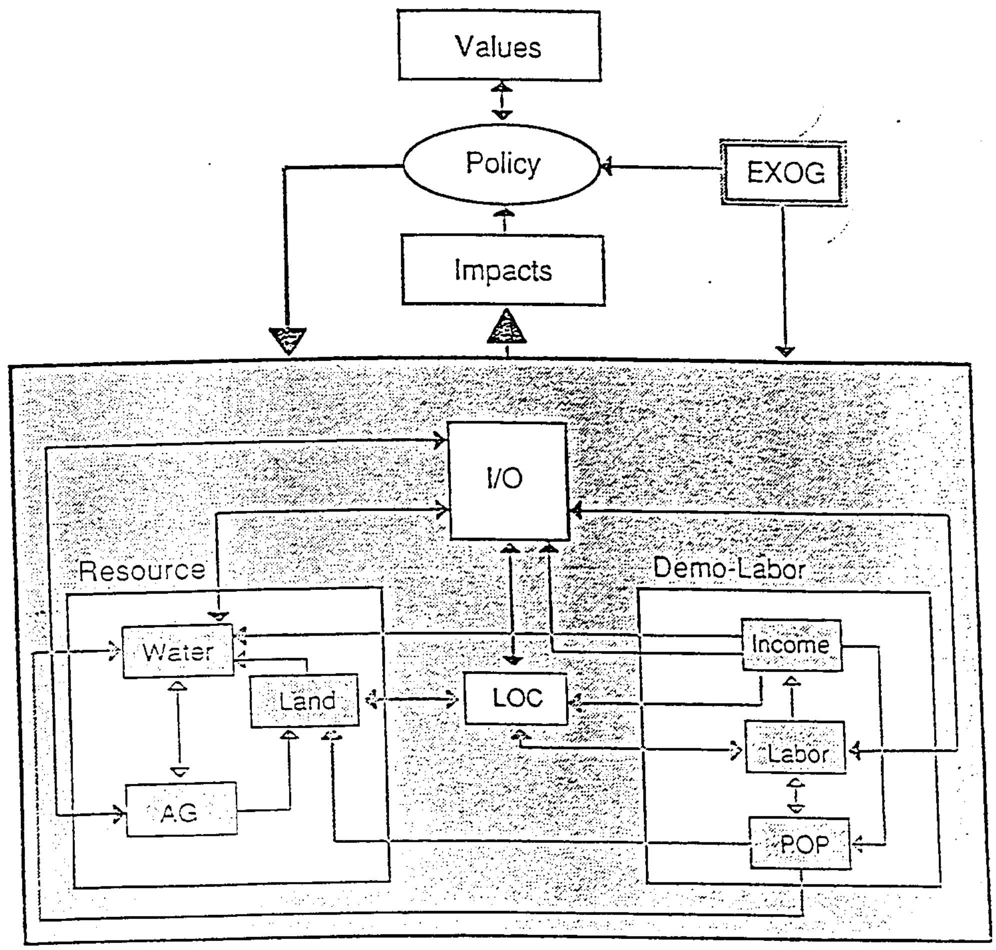


Fig. 1. Modular integrated framework.



Integrated Framework for Water Policy Analysis

Research Directions for Spatial Decision Support Systems:

A Position Paper for the NCGIA SDSS Initiative

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1.0 Introduction

Traditional approaches to solving locational problems range from the application of ad hoc gestalt-like decision processes, to the use of simple rules that narrow the number of alternatives that must be examined, to optimization programs which are capable of evaluating more alternatives in minutes than a human decision-maker could in days. In each case there are impediments to the widespread adoption of the approaches. Ad hoc approaches, for example, are difficult to defend if a plan generated by such a process is adopted. Likewise, although computer solutions are designed to optimize objective functions in which an attempt is made to capture essential characteristics of the problem being examined, many locational problems contain aspects which are not able to be measured adequately in a form that is suitable for optimization algorithms. In addition, currently implemented locational analysis systems typically require an expert analyst to operate them. This presents a barrier to decision-makers who must translate the problem into a form that can be understood by experts who, in turn must translate their understanding of the problem into a form that can be modelled by software. This prevents decision-makers from directly interacting with the problem and may prevent them from discovering how intermediate decisions affect final outcomes. Such practices also effectively preclude the application of domain-specific knowledge that the decisionmaker may have about the problem being examined. Finally, existing computer solutions to locational problems are notoriously time-consuming, despite ongoing efforts to improve the computational efficiency of algorithms (e.g Densham, 1990). Such computational complexity can make it impossible to engage in interactive, iterative problem solving for large applications. Decision support systems must overcome these shortcomings if they are to be applied routinely to important social and economic problems.

2.0 Requirements for Future Systems

There is a need to develop new systems of analysis which will have the following general characteristics:

1) The system must enable decision-makers to bring their theoretical expertise and personal experiences into the problem solving process. Problems of objective function specification can be overcome by incorporating the expertise of decision-makers into the solution process, and by enabling decision-makers to alter solutions based on their pragmatic experiences.

2) Different kinds of knowledge required to solve location problems must be elicited from experts, computed, stored and accessed by the system to improve decision quality and system performance. This knowledge can reduce the role that analysts now play, and will enable the decision-maker to work directly with the system.

3) Advances in software and hardware technology must be exploited to improve the decision-making environment, and to improve interactive system performance.

Although each of these characteristics is important for future SDSS development, the main focus of this paper will be placed on the final characteristic. The next section contains a brief description of an approach for storing and using different kinds of theoretical and practical knowledge about locational problems that can be used to improve the effectiveness of locational decision-making. The third, technological, aspect of improving SDSS will require new ways of conceptualizing system development, with the ultimate goal of supporting the first two system characteristics. Object oriented programming presents a useful environment in which to construct systems for spatial analysis. Parallel processing provides an additional avenue of research for improving the performance of systems designed to support spatial decision-making.

3.0 Knowledge-Based Decision Support

If users are to bring their expertise to the solution of spatial problems, their capabilities for controlling decision-making processes must be improved. This will involve the design of new user interfaces, and effective ways for managing the application of models to problems. This can be accomplished by a model management capability, which can be either manipulated directly by the user, or controlled by the system. If the system assumes this task, then a knowledge-based approach to providing decision support must be adopted.

A knowledge based spatial decision support system should contain knowledge that can be used to guide the user in the generation and evaluation of alternative scenarios as part of the decision-making process. In fulfilling this role the system should provide a mechanism for generating a plan, or a series of plans, that are theoretically sound. Such a mechanism is called a metaplanner (Armstrong, et al., 1990). Complex spatial problems can be solved by decomposing them into a set of subproblems, which can then be systematically evaluated and solved under the control of the metaplanner and the user. In each instance, the system must access a knowledge base that contains knowledge about the physical characteristics of the problem, knowledge about location theories, and knowledge about available solution mechanisms, and how they function under various conditions. When this last kind of knowledge is applied, system performance can be improved because unnecessary elements of the decision process will not need to be examined. In addition, the system will fulfill roles that heretofore have been performed by analysts. Knowledge can be represented by a set of objects which can be organized logically to facilitate processing.

4.0 Object Oriented Programming

It has been a common practice to abstract reality in the form of coordinates (e.g. nodes and links) to facilitate the processing and display of spatial data (Armstrong and Densham, 1990). Such abstractions can be defined as objects and thus, object oriented programming can be used to construct interactive systems for locational problem solving. The decomposition of a problem into objects has the additional benefit of creating modular, reusable software components. This attribute makes object oriented approaches suitable for problems that are decomposable into subproblems.

Object oriented programming makes use of information hiding, and bundles together data describing the state of an object (instance variables) and the processes or behaviors that the object can perform (methods). Objects communicate by sending messages, and each object has a distinctive public interface which determines the kinds of messages to which it can respond. Object oriented programs, therefore, often behave by sending messages among objects, and when an appropriate message is received by an object, a method is invoked to perform an operation, upon completion of which, an additional message, or set of messages is transmitted to other objects.

In object oriented environments different classes of objects can be defined (Armstrong et al., 1989). Through inheritance new specialized classes can be constructed which will have the characteristics of a less specialized class. Instance variables and methods can be inherited, and this greatly reduces software coding time; this characteristic coupled with modular programming features makes object oriented languages well-suited for the development of prototype systems (Parsaye, et al., 1989). Spatial objects contain in their instance variables the geometrical descriptions of entities used in locational models. In addition to geometry, however, objects contain methods to compute, on demand, needed values such as the distance along a network chain at a given level of precision. Analytical objects, on the other hand, contain information about locational problems which can be used to improve the computational effectiveness of the system. Densham (1990) describes how these structures can be used to reduce computation; Armstrong et al. (1989) describe an object oriented approach to their implementation.

An additional capability of object oriented systems is the ease with which graphical user interfaces can be implemented. Each object can be assigned a graphical identifier, or icon, and can be manipulated through the user interface. These nonprocedural event-driven interfaces will enable inexperienced users to invoke methods and algorithms as part of a broader decision process and may simplify the management of models used to solve various subproblems. In addition, a graphical environment will enable the visualization of subproblems and solution scenarios, which will allow decisionmakers to effectively evaluate alternatives.

In summary, object oriented programming can be used to: 1) implement locational analysis algorithms, 2) store knowledge and information about the characteristics of the problem, 3) store plans for decision-making processes, 4) implement model management capabilities, and 5) improve visualization of problem solving processes and results.

5.0 Parallel Processing of Spatial Problems

Microcomputer-based workstations will continue to be the preferred platform upon which to base SDSS for well into the next decade. Although these workstations are continually becoming more powerful, and some advanced processors are using pipelining, they are normally based on a sequential (von Neumann) architecture in which there is a single instruction and single data stream (SISD). Incremental increases in performance also are likely to be expensive. With a given level of technology, however, large gains in performance can be realized if several processors operate on a problem simultaneously. This parallel approach to locational problem solving can be implemented in several ways. Most simply, several processors each can be used to generate an alternative scenario for a decision-maker to evaluate. A more complicated approach will allow an individual scenario to be executed at very high speed by dividing the problem into parts which are then executed in parallel. A multiple instruction multiple data (MIMD) architecture appears to be especially promising for such an endeavor.

Before a problem can be processed in parallel it must be subjected to concurrent decomposition which involves two main tasks: domain partitioning and update ordering. Domains may have atomistic elements beyond which further decomposition cannot take place, but the ultimate decomposition will specify the granularity of parallelism for the problem. Domain decomposition proceeds by evaluating whether the problem is homogeneous, in which case each member of the domain requires identical amounts of computation, or inhomogeneous. Inhomogeneous problems require additional work to acheive balance among processor workloads (Fox et al., 1988). Domains also can classified with respect to the regularity of their geometry. Note, however, that problems are rarely found which satisfy each criterion exactly; most problems exist along a continuum of homogeneity and regularity.

The use of analytical and spatial objects can simplify the process of decomposition. In this case, the objects are used to help define the granularity of parallelism. In addition the use of objects helps to reduce data dependency, a major problem in implementing parallel algorithms. Such dependencies occur when processing that occurs on one node, depends upon the completion of a task on another processing node.

6.0 Conclusion

Future research on SDSS must allow location theory, and the considerable knowledge of domain experts to be applied to the solution of spatial problems. This can be accomplished by using an interactive, knowledge-based approach to the development of new systems. Along with this increased application of knowledge, future systems must enable the user to effectively interact with the solution process. This will require improved graphical user interfaces, and the application of new computer architectures to speed the process of scenario development. In each case, object oriented approaches can be used to speed system development.

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Developing a Decision Support System for Locating Emergency Facilities in a Congested Environment

by

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A position paper prepared for the specialist meeting for the sixth research initiative of the NCGIA, on the topic of Spatial Decision Support Systems

The 80's generated significant interest amongst Operations Researchers and Management Scientists on the topic of facility location of emergency facilities in a congested environment. The motivation cited by various authors for studying such situations is the increasing percentage of calls to emergency facilities (police, fire, ambulance) that encounter either a queueing delay, due to the nonavailability of a server (facility) at the time the call arrived, or to which a nonpreferred server is dispatched, due to the nonavailability of the preferred server. Emergency facility service systems increasingly work in a congested environment, due to increased demand due to urban migration from rural areas and due to budget cuts in most major metropolises in the United States (U.S.). These factors are expected to continue till the turn of the century, and hence most emergency facility service systems in major metropolitan areas in the U.S. can expect to operate in a congested environment through the 90's.

Due to the rich array of mathematical models and analyses developed by researchers and due to the projected congested environment, the time is ripe to develop a decision support system for locating and deploying emergency facilities in a congested environment. There are three key elements that have to be addressed to successfully do this:

(a) A comparative study needs to be performed of the existing models for locating and deploying emergency facilities in a congested environment.

(b) A "super" model needs to be developed, based on the results of the above cited comparative study.

(c) An expert system needs to be developed to convert the results of the models into a usable form.

To perform a comparative study of existing models, we propose to develop an experimental design framework derived from "real" data to monitor the performance of the models across a broad range of operating conditions. The goal of this study would be to derive generalizable conclusions about the circumstances under which a model does or does not perform as desired. Analytical tools such as computer simulation and design of experiments from statistics would prove useful in this regard. This task is complicated by the fact that the existing models have significantly different data requirements, and hence the experiment has to be designed in a way that creates data for the models without unduly favoring a particular model. As a result of this comparative study, it is hoped that a "super" model for locating emergency facilities in a congested environment can be developed and analyzed. This "super" model together with all the existing models will form the "black box" of the proposed decision support system.

One of the most important requirements of a decision support system is its capability to assess sudden changes in the system, synthesize potential responses, select among responses, implement selected ones, and monitor success in complex, unpredictable, rapid-response decision environments. We will develop a rule-based system, using Artificial Intelligence methodologies, to convert the locations and deployment strategies suggested by the models into a usable form, by accommodating the host of real-world factors that simply cannot be captured by a simplistic mathematical model. A separate rule-base will be developed for the application areas of police, fire, and ambulance. Interviews and responses to questionnaires will prove useful in this regard, as will a review of the literature regarding how practical location decisions are made in these environments.

A tentative timetable for these activities is as follows:

1. Comparative study of the existing models; 03/90 - 08/90.

2. Development of the "super" model; 09/90 - 10/90.

3. Comparative study of the "super" model with the existing models; 11/90 - 12/90.

4. Development of the expert system for the police environment; 01/91 - 02/91.

5. Development of the expert system for the fire environment; 03/91 - 04/91.

6. Development of the expert system for the ambulance environment; 05/91 - 06/9 1.

7. Synthesis of the decision support system for the police, fire, and ambulance cases; 07/91 -08/91.

The research will be conducted by Dr. Rajan Batta and by a Ph.D. student in the Department of Industrial Engineering, SUNY at Buffalo. They will be assisted in their efforts by Dr. Rex Kincaid, a faculty member in the. Department of Mathematics in the College of William & Mary, Blacksburg, Virginia. The results of this research effort will be reported in journal articles and possibly in the student's Ph.D. dissertation.

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NCGIA INITIATIVE 6

SPATIAL DECISION SUPPORT SYSTEMS

POSITION PAPER

DECISION SUPPORT FOR LAND USE-TRANSPORTATION PLANNING BASED ON SPATIAL INTERACTION-ALLOCATION MODELS

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Decision Support Systems (DSS) provide formal procedures for the application of highly-structured and/or well-structured models to poorly-, ill- or loosely-structured decision problems. Even within the more restrictive domain of spatial decision-making, the range of possible DSS's is enormous and it is thus necessary to narrow the area of concern to particular models. In this note, the models are those dealing with spatial interaction and allocation which have proved relevant to specific facility location, particularly retailing as well as to more general land use-transportation planning. Nevertheless, the range of decision problems to which these models might be applied is still considerable, and I believe that one of the aims of the workshop should be to define this range and to begin to identify principles for good model design and application, consistent with advances and conventional practice in the development of new methods for analysing and visualising geographic data.

One very obvious difference between the development of GIS and the identification and use of well-structured models in spatial decisionmaking relates to the specificity of the various systems available. It is most unlikely that any GIS could be extended to embrace the functionality posed by land use-transportation models for example, because the structure of such models imposes quite severe constraints on the way data needs to be represented, analysed and displayed. Although it might be possible to loosely-couple GIS with appropriate DSS based on spatial models, it is more likely that relevant Spatial DSS (SDSS) need to be designed virtually from scratch in that the model
structure and the way this is exploited and used in spatial decisionmaking, policy analysis and planning, requires purpose-built software. Well-structured models impose very strict limits on data and its representation while the decision problems of relevance manifest enormous variety concerning their 'ill-definedness' in different problem contexts. The way in which well-structured models combine with ill-structured problems produces another highly variable dimension in the way users, in their various guises as expert professionals and decision-makers, use such models in decision support. All of this suggests that although many of the accepted principles and practices of GIS and GIA are undoubtedly relevant to SDSS, the nature of the models, the problems to which they can be applied and their broader contexts are likely to dominate the design of appropriate software for such systems.

Therefore in the workshop, I would like to see the following issues addressed:

1. The variety of ill-structured problem contexts in which SDSS might be applicable.

2. The extent to which highly-structured models and techniques can be effectively exploited in poorly-structured problem contexts.

3. The ways in which such models and decision problems in 1. and 2. interact, and the design considerations for SDSS which spin-off from such interactions.

4. The ways in which existing GIS and GIA can be used in elaborating good design principles for SDSS.

5. The ways in which existing software can be exploited for SDSS, particularly that involving spatial database design.

6. The ways in which other NCGIA initiatives in database design, visualisation, map generalisation and so on might inform SDSS design.

I believe that to elaborate the above, it is necessary to restrict the domain of problems and models considered, as the workshop leaders Densham and Goodchild have proposed.

I consider that in comparison with the development of GIS and GIA which have so far been relatively uncontroversial, the development of SDSS is much more problematic. There is no wide consensus, for example, concerning the use of computer models in policy-making, nor is there any agreement on the way spatial decision problems should be defined and approached (Batty, 1989). This suggests that SDSS systems should incorporate great flexibility in their design, particularly in the way they might enable the user as both analyst and decision-maker to interact with the models available in the system, as well as in framing the way such models might address the problems in question. Thus, particular attention needs to be given in SDSS to how users can design models relevant to particular contexts as well as to the user interface necessary to effect good design. In short, it should be possible in every SDSS for the user to adapt the system to the specific constraints imposed by the problem in hand, and this might suggest the need for SDSS 'shells'.

I believe it is the role of the NCGIA to begin to demonstrate some of these ideas to the policy-making community at large, and that such demonstrations should concentrate on those models in which the members of the Center have the most expertise. Clearly spatial interaction, location-allocation and such like models are ideal candidates in this regard. In my own case, I consider the time is ripe to explore appropriate SDSS based on those spatial interaction-allocation models which are consistent with both the macro-statistical approach of entropy and information-minimising and the micro-approach of utility maximising. At the core of such a SDSS, there would be

1. Models which could be easily constructed by combining and aggregating basic spatial interaction modules.

2. A limited range of problems contexts associated with the design of certain model types, such as those used in retailing, in transport policy analysis and so on.

3. A functionality which could exploit the fact that such models can be 'calibrated' to data using conventional statistical estimation, or 'solved' in their optimising form.

4. A potential facility for embedding the optimisation approach to such modelling within the wider 'Optimisation' posed by the decision-making process itself.

5. The appropriate use of database design principles which would enable such decision support to be coupled to other information systems and databases.

6. Appropriate user interfaces enabling data, model analysis, and policy analysis to be visualised clearly and easily.

Such a system should have a 'learning' facility as well as a model design facility. Because of the ill-defined nature of the problem context as well as the controversial nature of much spatial modelling, users should be able to interact with such systems by not only designing and applying appropriate models but also by enabling exploratory analysis to be carried out, thus learning about the limits to the DSS in question. It should be possible in strategic, broadbrush planning, for example, to enable users to interact with the system without assuming that the system is anything other than a learning device. Moreover, such systems should be so constructed that novice users could become proficient users solely through their use of the system. The system should be designed with the very best software engineering practice in mind: it should be user-friendly, enable extensive visualisations of model inputs (data), outputs and model processes, and it should be configured with extensive display, report generation and help facilities.

For example in the case of spatial interaction modelling for strategic land use-transportation planning, such models can be designed at a variety of spatial scales using a variety of economic and demographic processes to effect appropriate coupling of spatial interaction modules. Such models can be fitted to data through both statistical and mathematical programming techniques, while also enabling clear and consistent cost-benefit indicators to be developed for the evaluation of alternative plans and their sequential optimisation (Batty, 1978). Such SDSS must incorporate the notion of nested optimisation, in which the principles of optimisation range from their formal expressions in the optimisation theory of spatial interaction, to much looser and informal processes associated with good model design on the one hand, and good decision-making on the other. What this implies is that SDSS should be flexible enough to enable 'formal optimisations' as well as 'heuristic satisfying' at a variety of levels of application.

The wider context in which such SDSS are used must also be scrutinised. I consider that it is the role of the NCGIA to demonstrate how such prototype systems might be both designed and applied, as well as how such systems might draw on best practice in GIS, GIA, spatial database design, computer cartography and visualisation amongst other initiatives at present being pursued by the Center. Moreover, the development of various SDSS in practice must also be critically assessed if potential new approaches to spatial and geographic systems analysis are to be realised.

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SPATIAL DECISION SUPPORT SYSTEMS:
A Personal Agenda for a Research Initiative

(Prepared for NCGIA Workshop,
Santa Barbara, USA.)

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Personal Warning!

In our Information Technology age, many commentators have highlighted the significant potential of recent developments in information and communication technologies. While much progress has been made through successful implementations of various types of computer-based information systems, there continues to be exaggerated claims and unnecessarily obfuscating jargon and hype.

In the computing world, Decision Support Systems (and so called Executive Information Systems) are the current vogue; in the business world, there is increasingly an external orientation with organisations recognising the strategic importance of marketing. (Both of these trends can be linked to the increasing "market orientation" required of academia - often at the neglect of longer term, fundamental research.) Finally, in geography, today's preoccupation seems to be with GIS (which, from my experiences, do not necessarily support decision-taking!

For a workshop entitled "Spatial Decision Support Systems in Marketing", there could be a real danger of further misleading "black holes". The specification of any meaningful research effort in this applications domain must be driven by marketing problems and the needs of marketing management. Notwithstanding the above, it is an exciting and important area (and I wish my schedule would have allowed me to participate directly in the Workshop!

Introduction

Densham and Goodchild (1989) correctly question and refute the implicit, if not explicit, conventional wisdom that Geographic information Systems (GIS) are necessarily useful and relevant for decision-making (see also Beaumont (1990)'s discussion of "where GIS is located" in terms of computer-based information systems). Notwithstanding important variations in their design, fundamental differences between GIS and Decision Support Systems (DSS) exist in terms of both the problems that they can address and, more significantly, the context in which they can support the decision-making process.

Over the last twenty years, in the computer-based information systems' literature, DSS have received much attention since their introduction by Corry and Scott Morton (1971). For real progress on spatial DSS in the 1990s, geographers must avoid the "trap" of debates about alternative definitions and classifications (see, for example, Alter (1977) and Cowan (1988)); the developments in and experiences of computing science and business and management in the 1980s are most pertinent.

As with any investment, the ultimate appraisal of any DSS must be in terms of its enhancement to the effectiveness of the decisions and to the efficiency of the decision-making process. In this note, a number of research issues are highlighted; the focus is on the DSS capabilities, rather than the broader context of the decision-making process (see Stabell (1983) for comparison).

At the outset, however, it should be stated that DSS can, and indeed should, change decision-making because, they not only speed up the process and but also make the decisions more explicit and clearer. in practice, this emancipatory potential raises questions about information absorption, and, the real difficulties of being less able to avoid taking "hard" decisions. However, to date, DSS have not had a significant impact on the way managers make decisions. To be deemed successful, in the future, DSS should have profound impacts on managers' activities and should be integrated into an organisation's decision-making culture and process (rather than merely "bolted on"). in spite of recent progress made through the introduction of so-called Executive information Systems for senior management, it must be appreciated that current usage of DSS is predominantly by "middle" management in functional areas such as marketing, finance and operations.

Discussion

This discussion is structured around DSS capabilities. The framework is helpful to present ideas; it is not suggested for the design of spatial DSS. To illustrate the ideas, brief reference is made to applications in marketing and retailing. It is believed that the focus should be on the functional capabilities of a support system in relation to management's needs for data and analyses.

Without getting embroiled in definitions (particularly about the concept and what constitutes a DSS), it is sufficient to state that DSS involve semi-structured and/or unstructured, simple and/or complex problems that can be explored in an interactive or recursive manner by the decision-makers. To allow this kind of decision-making, traditionally, four separate, albeit linked, fundamental capabilities of DSS have been recognised (see, for instance, Montgomery and Urban (1969)):

- database;
- analysis;
- decision models;
- interface.

Individual systems vary in the relative emphasis given to these capabilities; figure 1 provides a framework to indicate issues for a research agenda.

While it is appropriate to discuss these capabilities separately, it is also helpful to consider them together. By emphasising different capabilities or combinations of capabilities, it is possible to begin to understand the different types of decision-making contexts that can be supported by DSS.

In the business world, for instance, two particular types of DSS are particularly important:

- spreadsheets;
- database management systems.

As figures 2a and 2b indicate, spreadsheets combine the ?'decision models" and "interface" capabilities, and database management systems combine the "database" and "interface" capabilities. this description characterises the basic and primary characteristics of these DSS systems.

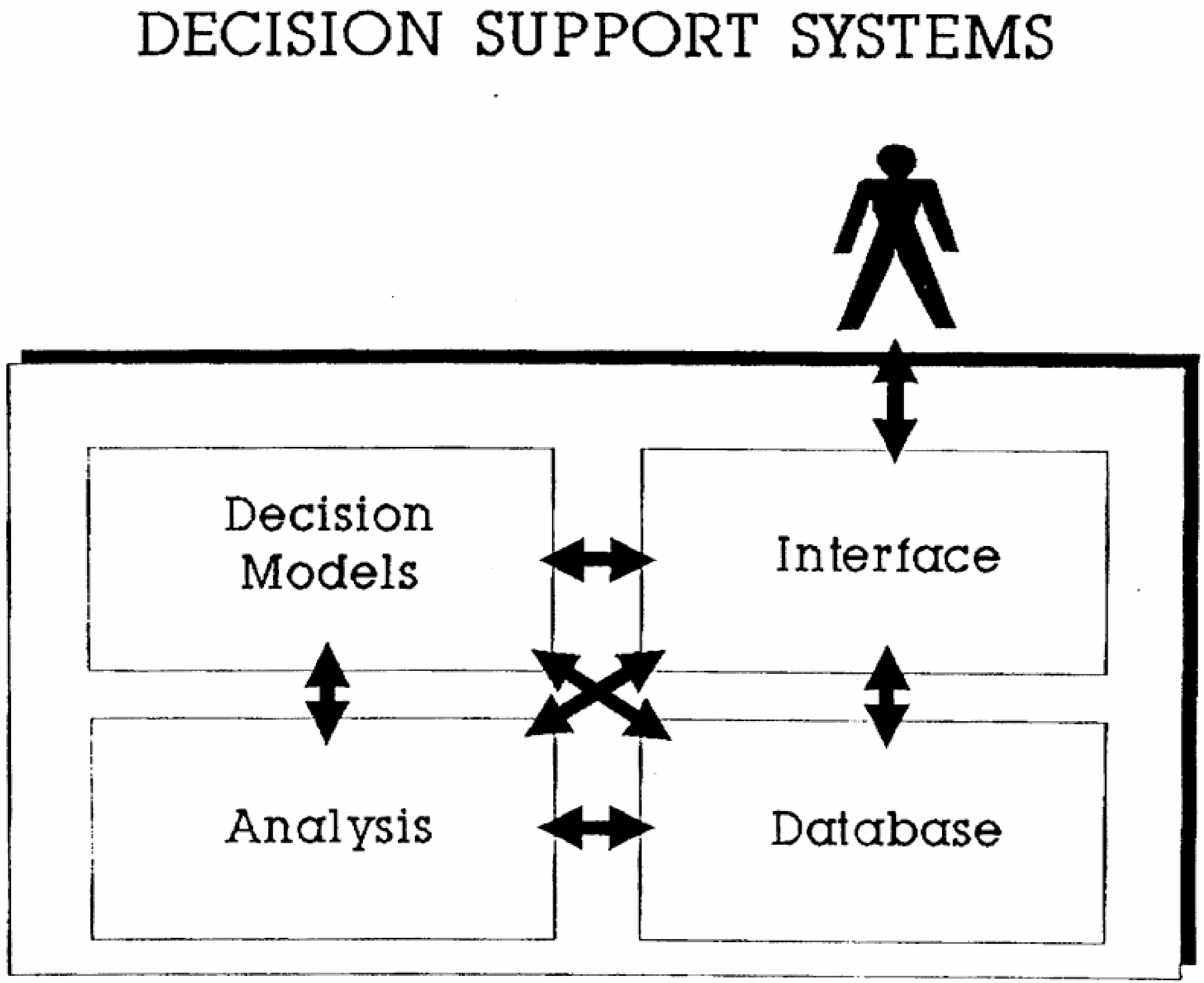
DECISION SUPPORT SYSTEMS
Decision Models
Interface
Analysis
Database

Figure 1: DSS

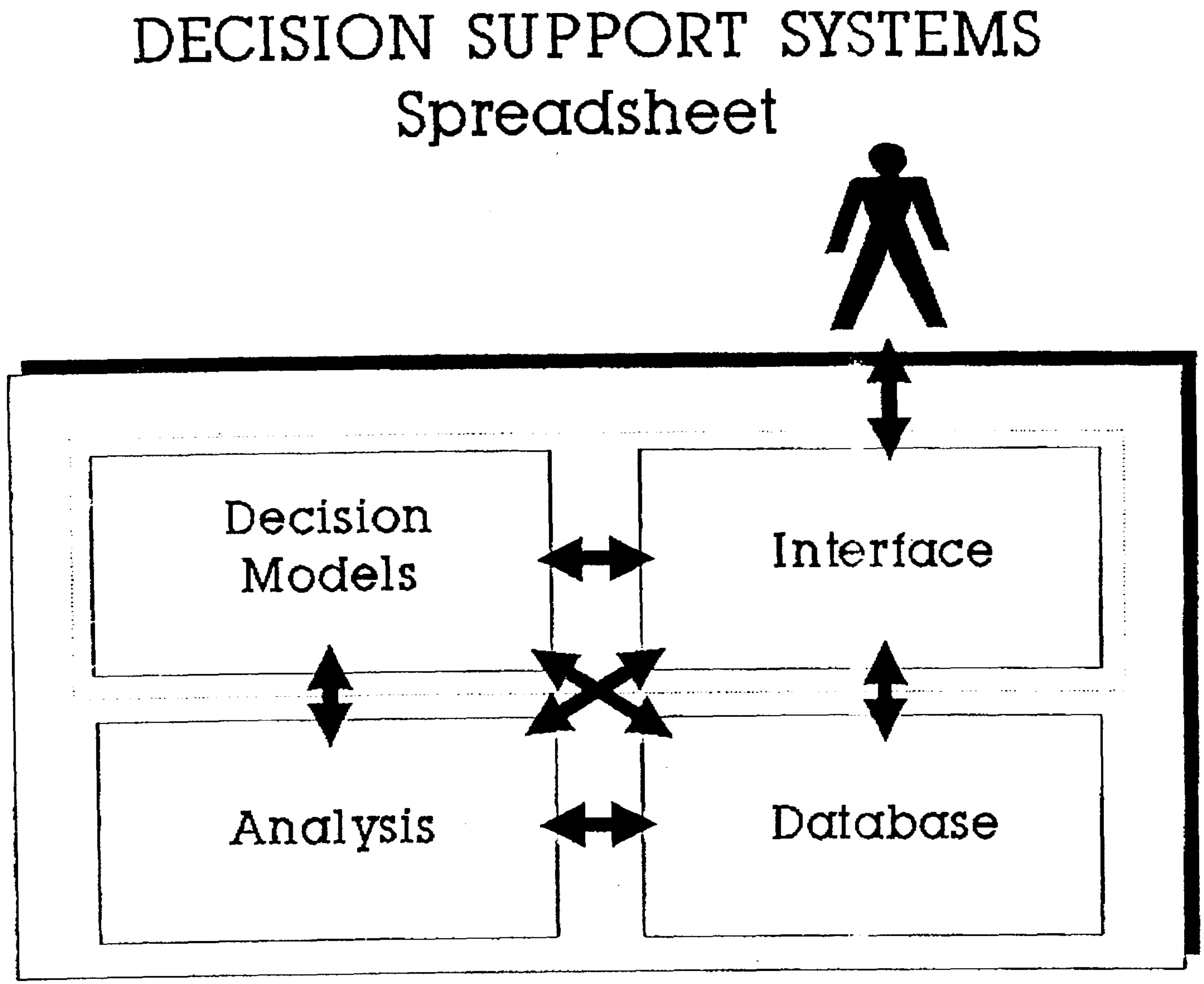

Figure 2a: DSS Spreadsheet

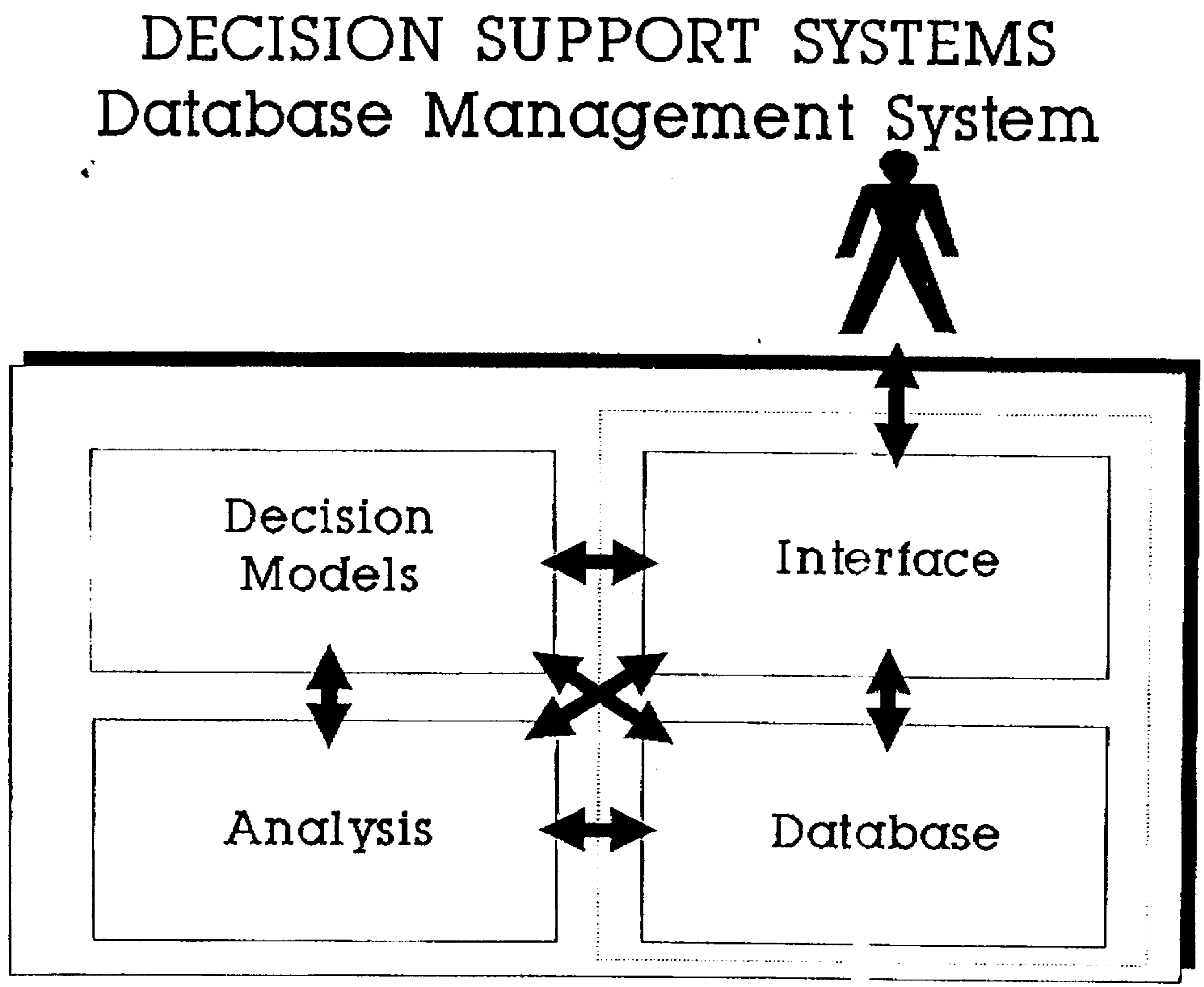

Figure 2b: DSS Database

Spreadsheets are a matrix of rows and columns that undertake calculations on the cells. The primary application area is financial modelling, budgetting and planning. A spreadsheet model is defined in terms of interrelated variables, and automatic recalculation facilities permit sensitivity analyses. Graphics and report generation facilities are also important. There are usually only limited database capabilities (and note the so-called "integrated" packages with wordprocessing), and they do not have ad hoc analysis capabilities. Even with the availability of macros, only simple mathematical and statistical analyses can be completed, usually in a contrived way. Recent versions have begun to extend and enhance their capabilities. For example, in terms of spreadsheets, Excell makes use of the Windows environment. Release 3.0 of Lotus 1-2-3 builds on earlier versions, 1A, 2, 2.01 and 2.2; the release of 1-2-3/0 running under OS/2 is anticipated shortly with worksheets as icons in a window and other attractive features.

As indicated by thoir name, database management systems offer facilities to access and manage large databases and to create reports and graphs from the database. Limited analyses and modelling can be completed.

Within this framework of DSS capabilities, it is possible to view the majority of GIS as orientated towards the "database" and "interface" capabilities - database management with automated cartography. Moreover, while a number of people have begun to argue strongly that the lack of analytic capabilities in CIS is a major shortcoming, this framework also suggests that insufficient attention has been given to "decision models". As stressed at the beginning, it cannot be assumed that GIS are useful and relevant for decision-making. Given the usual learning pattern, these constraints do not permit managers to evolve through a DSS by performing increasingly complicated analyses.

Research Agenda

The research agenda for the future should be driven by the development of DSS with more comprehensive and "integrated" capabilities. System evolution should be anticipated because DSS deemed "useful" will generate pressures for enhancements! Their design must be driven by user needs and have early user involvement.

For convenience of presentation (and following Densham and Goodchild's (1989) format), brief comments are made separately on the four DSS capabilities described in the previous section.

Interface

The general interactive multitasking developments of recent years and 3-D graphics are important base standards for the user interface.

Artificial intelligence developments could make systems easier to use, for instance, by helping to select appropriate statistical methods for forecasting purposes (see also Luconi, et al's (1986) discussion of "expert support systems", which do not assume management abdicating their decision-taking to computers).

A new DSS application area, particularly linked to group decision-making, is communications support, going beyond say electronic mail to include graphics, video and voice.

While there is much scope to assist users through Human-Computer interface developments, experience indicates that the most important requirement is relevance and usefulness for the manager's Job. if a manager gets what he wants and needs, he is usually willing to put up with non-"user friendly" interfaces.

Analysis

If it is accepted that most GIS are deficient of spatial analysis capabilities, there is a wealth of experience in this area to enable the incorporation of spatial statistics and of optimisation and simulation models (see, for example, Dixon, et al's (1987) proposals for a sub-routine library).

As the power of information systems increases over time with the collation of historical data, a special plea is made not to forget spatial time series methods.

Similarly, fuzzy techniques could be appropriate for unstructured, complex problems.

Explicit consideration should also be given to data accuracy and error propogation in any analysis.

Database

Given apparent fundamental difficulties of the relational model for handling spatial data, current research on an object-oriented approach appears to have potential.

Hypertext's flexibility may merit attention for structuring data and for providing a powerful integral user "help" system.

Analysis should not be related exclusively to numerical data; qualitative data can be highly relevant in marketing, and expert system developments may be pertinent here.

Decision Models

while a statistical and mathematical analysis capability should provide useful information for decision-making, an explicit decision model capability would be extremely relevant. It is possible to envisage different decision domains, such as marketing, financial management, branch location and distribution, which have a range of appropriate modelling facilities such as "what if…" options, goal seeking routines and margin analysis.

Marketing managers, for example, need to evaluate alternative options and the financial modelling capabilities and specific functions of spreadsheets are very helpful (for instance, Albion and Hoff's (1988) book, which is used to introduce Lotus 1-2-3 at Harvard Business school, relies exclusively on marketing examples). marketing problems would include planning and monitoring of the branch network, competitive assessment, sales management (including key accounts), new product development and testing, branch positioning and market segmentation… .All have an explicit spatial dimension.

Spatial DSS should not only be developed; their applications domain should also expand. Elsewhere I have argued that,

> "… enhanced data availability and quality can not only improve existing analyses but also support new types of analyses" (Beaumont, 1988).

For marketing applications, the current emphasis on data status reporting with regard to sales, market share, price, ... should be complemented by a more analytic impact reporting on say price elasticity, advertising effectiveness and site location and merchandise mix.

Some Concluding Comments

Spatial Decision Support Systems are a significant and challenging area for geographic research in the 1990s. Within the context of the decision-making process, advances can be envisaged in terms of the different capabilities of DSS. However, there should not be any technological imperative, because the real impacts of DSS will not arise because of the characteristics of technology itself. There seems to be a growing gap between it's increasing power and the software tools/data availability and quality to exploit it.

The current lack of explicit attention to the decision-making process and organizational structure means that, at best, we have a limited comprehension of DSS impacts, or potential impacts, on working practices, roles, responsibilities and relations, the nature of tasks, ... (see Keen and Scott Morton (1983) for an organizational perspective on DSS)

To conclude, it is appropriate to broaden the discussion to highlight the context of IT capabilities in terms of both the decision-making process and organisational structures. Zuboff (1988), in a recent significant contribution on management thinking, extends the original and the currently predominant efficiency/productivity ("automate") argument for IT investment by recommending "informate"? with an explicit emphasis on the information content of administrative and productive processes in an organisation.

> "The distinction between automate and informate provides one way to understand how this (information) technology represents both continuities and discontinuities with the traditions of industrial history. As long as the technology is treated narrowly in its automating function, it perpetuates the logic of the industrial mathine that, over the course of this century, has made it possible to rationalise work while decreasing the dependence on human skills. However, when the technology also informates the processes to which it is applied, it increases the explicit information content of tasks and'sets into motion a series of dynamics that will ultimately reconfigure the nature of work and the social relationships that organize productive activity." (Zuboff, 1988, pages 10-11.)

Electronic Point of Sales (EPoS) systems, for example, have been introduced by retailers to automate their checkout and their stock control processes; the data can also provide actionable information for branch-level market analysis (see Beaumont (1990b for more details).

Figure 3 suggests two additional possible IT capabilities:

- “communicate";
- "transformate".

Information technologies have enhanced the effectiveness of communications in terms of speed, capacity and accuracy. Traditional perspectives on organisations, hierarchies and bureaucracy, are becoming obsolete in the IT age of networks and networking. Retailers, for example, are using this infrastructural capability to permit local branch-level action, while maintaining head office control.

"Communicate" also raises an important and relatively neglected research issue about Group Decision Support Systems. The systems developed in the 1970s and 1980s have been for individuals acting independently. To enhance organisational efficiency and effectiveness, further IT support must be developed for group workings (see, for instance, Huber (1984)). Discussions, negotiations, bargaining, ... with colleagues are important dimensions of decision-making, and they could be supported.

"Transformate" is used to indicate the ways in which IT are affecting competitive and collaborative forces facing organisations. while no evidence exists to support the assertion that IT can be a source of sustainable competitive advantage, IT does impact directly on industrial structures and ways of doing business. For example, shared ATM networks have enhanced service provision and home shopping is opening up new geographic markets.

In conclusion for GIS generally, there has been a great improvement in the awareness of the significance of efficient and effective handling of geographic data in a range of application domains. This real progress should provide the firm foundation for a research initiative on spatial Decision Support' Systems. Priority research areas should include:

- an organisation's decision-making context and the information requirements;
- the DSS capabilities, particularly "analysis" and "decision models".

Significantly, there should be the research capacity and interest available to ensure success in this important area. We should aim to be able to say something meaningful about organisational impacts of introducing and using spatial DSS, as well as attempting to design and develop enhanced spatial DSS. what are the critical success factors behind implementation of spatial DSS in marketing?

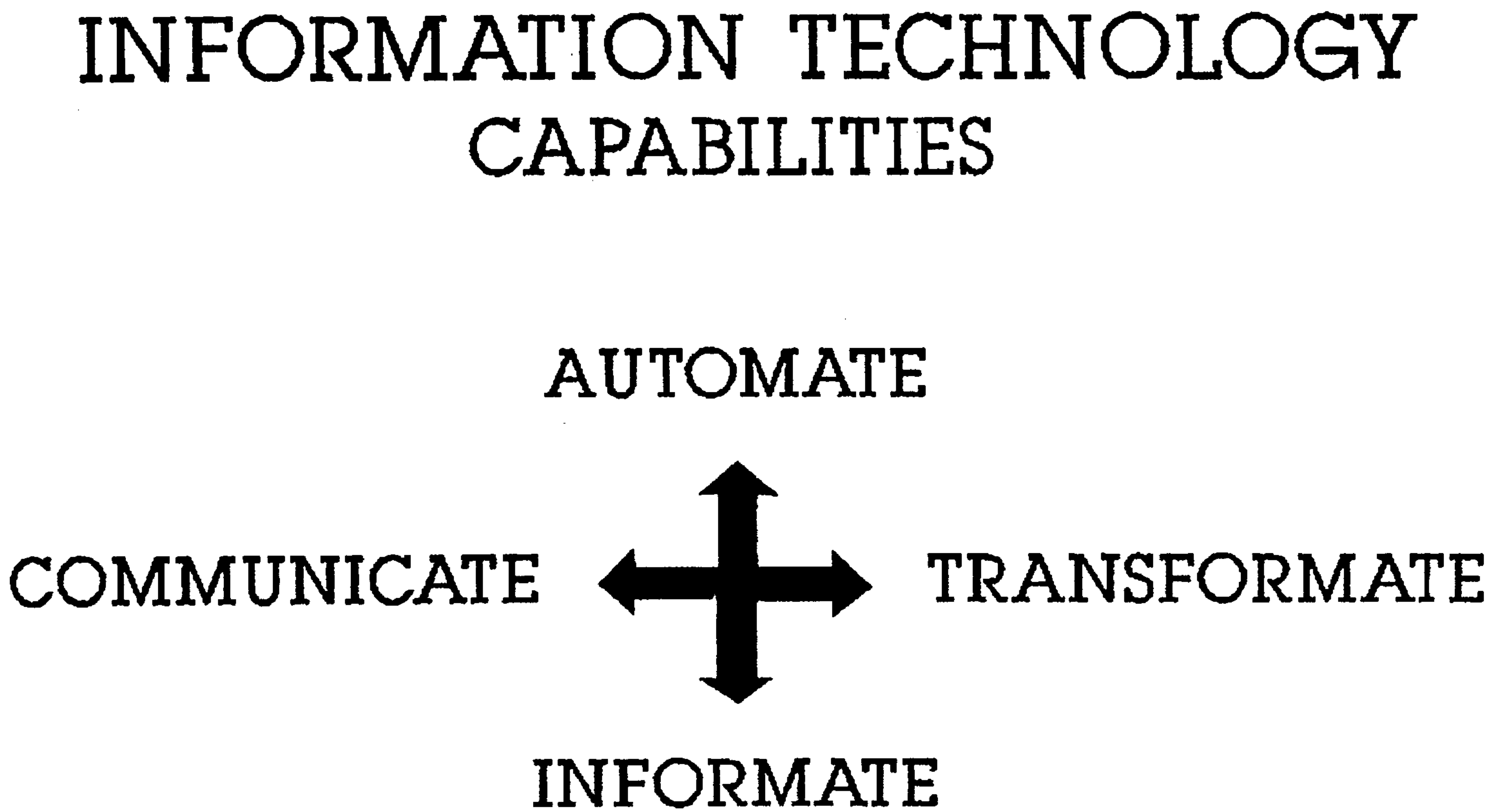

Figure 3: IT Capabilities

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Spatial Decision Support Systems **Richard Church**

It is hard to envision the successful application of analytic spatial models without incorporating the concepts and structures inherent in Decision Support Systems. In part space has already been incorporated, even though the name Spatial Decision Support System (SDSS) has not been used. For example, there are already a number of routing/shipping DSS's that are either available or under development. These DSS's address problems that are inherently spatial in character. These special purpose systems assist in reducing transportation costs and can be easily sold on the basis that their cost is less than the savings that will accrue in using them. One of the basic reasons for this new development is the availability of high quality graphics workstations on which the operator can see the results and interact by making special changes or adding constraints. For example, given a series of routes, the operator can use experience and judgement to alter/interact with the system to generate a final route plan. One reason that the "Desk Top" solution to such problems has become so popular is the fact that the routing models and the problem structures are defined on networks of nodes and arcs. This type of problem representation can be easily displayed with straight forward graphics commands. The fact that these software products exist attests to the benefits that can be gained in application.

It is not surprising that such special applications will form the first set of successful SDS systems, since they comprise a specific market niche. General purpose GIS's do not in general solve this type of problem. Much interest has been placed on the cartographic operations in general GIS's when the special SDSS's have been constructed with the algorithm as the central component. This means that the special systems provide faster response times, are frugal in code, and can be produced inexpensively compared to the large scale GIS. It is true that these special purpose application packages are stand alone systems that have limited potential for growth and flexibility beyond the specific application. However, in many instances they are preferable to the general-purpose GIS. Furthermore, as the spatial decision support industry matures, it is reasonable to expect that SDS systems will evolve into larger more capable systems which are not designed for one special purpose but can used to address a number of complex, ill-defined problems.

Specific Issues Concerning SDSS and Initiative 6

The basis for this meeting is to discuss and refine a research agenda for the National Center concerning initiative 6. The initial center invitation listed the areas of emphasis as marketing, retailing, location, and socioeconomic models. I would like to add to this list an additional problem area that is related to several of the above fields, namely districting or territory delineation. The task of identifying a new service location also entails defining a service area. Delineating a service area, along with political districting, school districting, turfing, etc. fall into a category of special complex spatial clustering problems that are not only related to several of the above fields already considered but also represent a special important problem area. Expanding the area of emphasis is done at the risk of making the scope too large. In this case I believe that there are a number of important spatial operations and SDSS issues that will arise from including this as a specific area on which some research emphasis should be placed.

One of the most important issues associated with an application is "problem definition in a georeferenced context." For example, consider the location of a fire station. Fire stations are usually located to cover demand zones, not individual property (see NYC Rand study or Public Technology Incorporated). The issue of demand definition and area representation in most applications is based on some level of aggregation. For example, the City of L.A. has 105 stations and 4,000 demand zones. It is not immediately clear that these zones are appropriate for the types of fire and EMS management Decision Making for which they have been planned. On the other end of the spectrum, Cadillac Motor Division analyzes urban dealership locations using a median model where each demand point represents an individual customer. A major research issue in the design of a SDSS is the need for consistent linkages between geographic data and models. This includes problem aggregation, sensitivity analysis, and error propagation based on model structure linkages with georeferenced data. This issue also involves the attendant problems associated with variable reporting zones.

One of the common traits of Decision Makers is the desire to gloss over uncertainty and to handle only those factors that can be easily defined and are somewhat certain. This is something that a lot of modelers Eke to do as well because this allows the definition of well behaved and well structured models. Unfortunately, this means that we all too often throw out the problem with the bath water. I believe that a major SDSS research area is the development of a methodology to address uncertainty in both the temporal, spatial, and problem definition domain. Related to the issue of uncertainty is the level of reliance on a model to generate "a" solution. What is necessary is to place the appropriate perspective on the value of a model and an optimal solution. Optimality exists for a well-defined mathematical construct. An optimal solution to a problem, adequately represented by a mathematical formulation using error free data, is indeed optimal. As we move from certainty in data and further realize that our assumptions are likely simplistic and our mathematical forms approximate, we realize that the quantitative model yields an optimal solution that may not be best for the real world problem. Further, it is possible that not all objectives have been uncovered. Accepting this should shift the general perspective in SDSS to one of generating good and significantly different alternatives not on defining optimal solutions. This issue should receive attention in the initiative.

Many GI systems utilize specially defined data base structures. These structures are designed to perform specific cartographic functions efficiently. In order to integrate models and data bases, one can either translate data into a format that is used in the model or one can redesign the model to inter-act within the spatial data base structure. For example, this could involve developing object oriented programs to perform location algorithms. In those instances where specific data structures have been designed to increase the efficiency of an operations research technique in solving a spatial problem, the resulting data structures tend to look similar to those used in GIS's. Thus an important research area is how to interface algorithms with GIS data structures and commands. Clearly, there could be benefits to both research fields. This research is also related to determining basic SDSS functionality along with defining efficient process in accomplishing such tasks.

SPATIAL DECISION SUPPORT SYSTEMS: A CASE OF THE GIS TAIL WAGGING THE ANALYTICAL DOG

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For fifteen years the author has worked as what might be broadly called a ‘quantitative geographer’, mainly in the field of urban and regional analysis. Some 5 or 6 years ago it became apparent that most of the methods that the author was working with were finding very little practical use in public or private sector planning. I was certainly not the first to wonder why this situation arose, indeed the literature on the 'failure' of quantitative methods ranges from the idealogical to the prosaic. However, convinced of their potential utility, it seemed an interesting challenge to seriously explore if there was a route by which organisations could be persuaded to adopt certain types of methods as a matter of course. In the subsequent period there has been, an immense amount of eye opening and a number of endearing memories. In the latter category falls the author's naivety in relation to organisations' needs and the way in which they conduct their business. In addition, what I discovered was that many organisations were attempting to practice 'regional science', often with little knowledge of the wealth of methods and techniques available, and almost always doing it badly!

At the same time as this was happening the embyonic field was beginning to develop, notably following the Chorley Report into the Handling of Geographic Information, published in 1987. What GTS provided for me was the capability of representing either existing and/or modelbased information in a very attractive and easy to understand form. I therefore have used GIS as an adjunct to spatial decision support sytems, rather than the other way round.

By adding GIS-type capabilities to our analytical tools a number of successful attempts were made to persuade organisations; to introduce systematic spatial analysis methods. This then led to the formation of a unit at Leeds j, called GMAP (Geographic modelling and Planning) which separates through the University’s own company. GMAP now works with a wide range of organisations in sectors such as retailing, financial services, the motor industry, the utilities, health care and government agencies. Clients include the Department of Health, the Training Agency, Toyota, W H Smith, Storehouse, Ford of Europe, Thorn EMI Whitbread, Kingfisher Group and Midland Bank, along with a Large UK supermarket group. For all these organisations we have developed spatial decision support systems that are installed in the clients headquarters. GMAP employs over 35 graduates from a wide range of backgrounds and is currently establishing a North American sister company. It is from this experience that my comments below are derived.

2 SPATIAL DECISION SUPPORT SYSTEMS AND GIS: TOWARDS A RESEARCH AGENDA

2.1 GIS AT LEEDS

The GIS research environment at Leeds draws on two decades of pioneering research into the development and application of spatial analysis methods, coupled with the successful harnessing and tailoring of powerful GIS presentational capabilities on PCs and workstations. This has led to the development of a distinctive style of intelligent, interactive applied geographical information systems? and we now have substantial experience in their widespread application. This history of GIS development has been supported both by research council funding (c 1 million at current prices)t and through a large and expanding body of contract research work with various large private and public sector organisations (c 2.0 million at current prices). The systems which have been developed have been applied in areas as diverse as urban planning, economic development,, retail and financial services, health services, energy resources and water resource planning. We are continuing to extend the range of application areas.

As a consequence of this experience, we are in a unique position (compared with most academic research groups) in that we have worked with and installed our distinctive analysis based GIS in many large organisations. From the experience of developing user-oriented GIS-based systems much of our current research is at the human-computer interface level. This is necessary to realise more widespread and effective uptake of GIS in decision support roles. I must emphasise that the issues here are non-trivial,, and currently probably represent more of a challenge than many of the 'technical' issues surrounding GIS. However, with some notable exceptions (this particular NCGIA initiative being one of the few) the majority of academic research in the GIS area is concerned with technical/software issues surrounding GIS as an end in itself.

2.2 SOME CONVERGENT TRENDS

A number of developments have created the 'enabling' environment which allows both the development of spatial decision support systems and, importantly, their transfer from a research and development arena to operational use within public and private sector organisations. Among these are:

(i) the development of GIS capabilities

(ii) the increasing ubiquity and power of the P.C.

(iii) the availability of an increasing amount of spatially referenced data, often electronically captured

(iv) more sophisticated modelling technology and increasing experience of model application

We can map these convergent and reinforcing trends on to a user environment that is becoming more receptive to the use of SDSSs. This has emerged through an increasing awareness of the potential of decision support tools, but most forcefully in areas like retailing and marketing through an Increasingly competitive trading environment, where marginal increases in advantage can bring spectacular results (note the experience of Tesco PLC in the U.K.)

In setting cut a possible research agenda I confess that it is underpinned by a belief, derived from substantial experience in attempting to transfer GIS technology into practice, that the environment and needs of potential users have to a signficant extent been ignored by the GIS 'industry'. Indeed, I would contend that most GIS application is currently driven primarily by available software technology: proprietary systems are being offered as a general purpose panacea to all user problems, with insufficient regard for specific needs. For applications in the AM/FM area, this may be appropriate. However, in the area of spatial decision support systems, I would argue that this strategy is ultimately misguided. One of the main considerations in identifying the research issues below is that only by focussing on the organisational context of GIS application and specific user needs will the long term dissemination of analytical GIS into non-academic organisations be assured.

Having read the papers distributed in advance of the meeting (Beaumont, Densham and Goodchild, Densham and Rushton) I am pleased to largely concur with their views? and that the sentiments expressed above are being echoed by an increasingly significant number of observers.

3 ELEMENTS OF A PROPOSED RESEARCH AGENDA

I have identified a number of areas that I fool are of importance from my own background and experience:

1. The organisational context of SDSS and GIS

Organisations vary considerably in their size,, focus and range of functions. Within an organisation there are a variety of potential users of geographical imformation, performing a range of tasks. This can be represented in an idealised way as in figure 1.

Currently, most applications can be located in the top left hand corner of this matrix, using proprietary software to undertake relatively routine tasks. The challenge is to move the applications towards the lower right hand corner of this matrix, where there is a greater need for decision support functions.

Research is required into the different types of user requirements and a better understanding of how geographical information and analysis is or could assist organisations in their management and planning.

2. GIS as a tool for decision making

At the strategic level, the use of decision support systems will embrace a wide variety of functions that reflect an organisation's activities and interests. It may well be that of these have an explicit geographical focus (especially if the organisation is a retailer, a bank, a health authority, etc), but there will be a range of functions that decision support systems are used for that are distinct from typical capability (although possibly related to it). Examples are economic evaluation methods, including cost-benefit, cash flow, and return rate calculations, and other project evaluation methods. These in turn will be related to other organisational activities - their Management Information Systems, Financial Planning, Capital Expenditure Programs, and so on. If GIS is ultimately to take a place at the strategic level, then it will need to be absorbed as a crucial component of more wide-ranging Executive Information systems.

I therefore feel there is a need to develop prototype Executive Information Systems, incorporating GIS and other decision support functions in a single, integrated system. I have not come across a single example of this being successfully implemented, although some of the applications that GMAP has embarked on have attempted to move towards this objective.

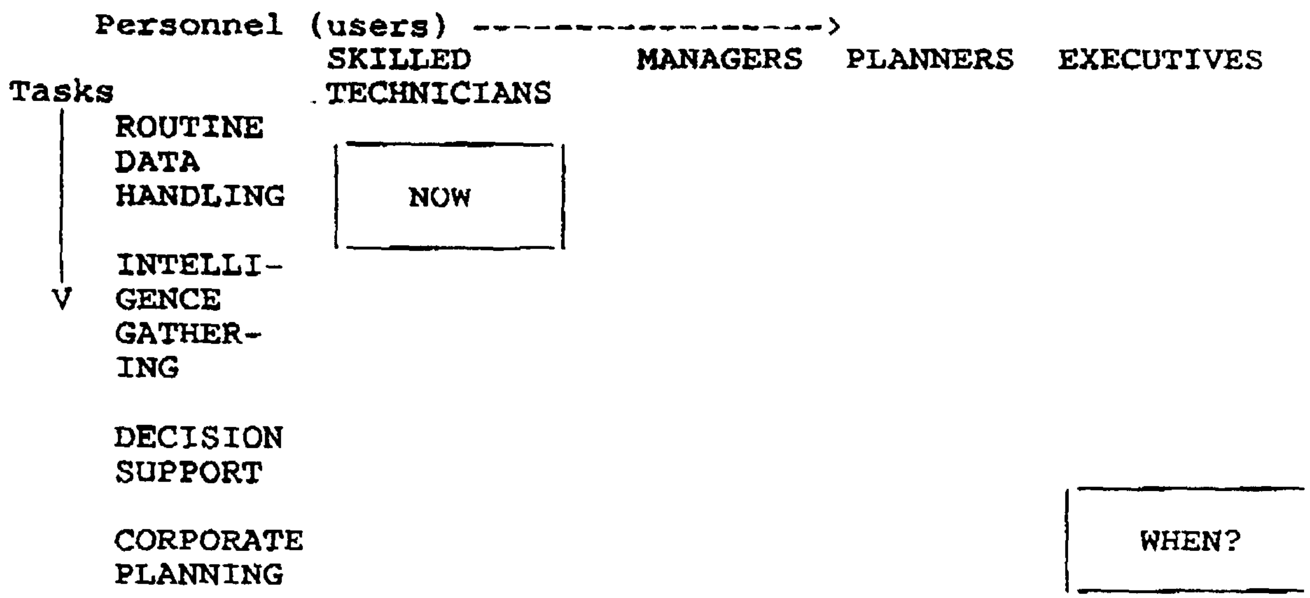

Figure 1. The organisational environment for GIS

3. Expert systems and GIS

Current generation analytical GIS can be accessed and interrogated quickly and easily through self-explanatory hierarchical menus, and a minimum of keystrokes. They exhibit high standards of professionalism in terms of being attractive, robust and easy to use, with context-specific help screens available as appropriate. However, it is clear that users do not always exploit the full potential of the functionality of such systems. This is particularly so in the analytically more complex, and ultimately more insightful, aspects. For example, an unduly restricted range of options is likely to be explored in modelling and scenario modules; and interpretative competence may be lacking and/or inappropriate tests pursued in statistical modules; in such cases the user may not only be left without useful results, but, more crucially, suffer a serious loss of confidence in the capability of the system as a whole. A further remediable of existing systems is their inability to respond to anything but already well formulated questions on the part of the user (ie they do not offer guidance as to possible approaches into general problem types).

I believe that a significant research effort should be devoted to the design and implementation of additional intelligence capability at the GIS user interface. This would require a more flexible, adaptive user interface - an intelligent, interrogative interaction which will enable the system not only to respond to already well formulated questions on the part of the user, but also guide less well articulated, higher level inquiries into meaningful exploitation of the system's functioning, and include informative diagnostics and interpretative capability, as appropriate.

4 Embedding GIS capabilities within an analytical framework

Tho fourth major area I would like to see explored (and there is evidence that this is now happening) is the integration of model-based methods and GIS-style capabilities. This is implicit in the three topics identified above, but I feel needs flagging as a separate area.

LINKAGES BETWEEN THE FOUR PROPOSED AREAS OF RESEARCH

I consider it appropriate here to emphasise the interlinkages between these proposed areas of research. In particular, the design of additional software intelligence needed for a more effective and versatile GIS user interface has to be informed and guided by the context in which the systems are ultimately to be used. It is difficult to see how it can be done effectively in ignorance of what type of decisions GIS can support, and in what organisational contexts these decisions arise. Indeed, one of the shortcomings of AI in the past has perhaps been the lack of substantive applications and context orientation. I look forward to discussing these and other issues in Santa Barbara.

SPATIAL DECISION SUPPORT SYSTEMS

Position paper prepared for NCGIA Specialist Meeting on sixth research initiative, Santa Barbara, March 14-18, 1990.

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1) GIS (as evidenced by commercial turnkey packages) is different from SDSS. Today's GIS packages are highly evolved toolboxes, most with hundreds of functions. Needless to say, they take weeks of training and months of experience to master. They strongly emphasize digitizing, editing and coordinate manipulation capabilities. There is widespread agreement that DSSs need to be simple and user friendly. The last thing decision makers need is training in digitizing, topological editing and map overlay!

2) Digitizing and the need for digitizing is and rightfully should be anathema to decision makers. A decision maker's job is to make decisions, not deal with the technical minutia surrounding data, geographic databases, and the need to digitize their own geographic databases. Digitizing should not be a prerequisite to use an SDSS. Perhaps one could even argue that digitizing should be a "forbidden" function for an effective SDSS!

3) The corollary to (2) is that for SDSSs to be successful, off-the-shelf geographic databases must be available. This echoes Goodchild's statement that "the lack of a comprehensive, current digital street network is a critical problem... 11 (Ref 1) This sentiment also emerges in Recommendation #2 of "Spatial Data Needs: The Future of the National Mapping Program". (Ref 2)

4) The specter warned against in the above Recommendation #2 -- that of a consortium of companies turning government geographic databases into a proprietary geographic data resource -- is happening right now; my company is a participant. In my opinion, 'this may not be as fraught with peril for SDSS users as the Mapping Science Committee fears.

5) The idea of a DSS Generator (Densham, Ref 3) is evolving rapidly in the private sector, with extensions to handle the particular geographic requirements of SDSS. Almost every commercial thematic mapper or GIS package has at least a macro language, intended for tailoring "canned" solutions for non-technical users. Some companies use structured subroutine libraries. At GDT we use a 4GL approach (Ref 4) to writing both specific SDSSs and all our internal systems for creating and maintaining geographic databases. Recently we've seen the appearance of a company (Ref 5) dedicated exclusively to selling a software package that I would term an SDSS Generator.

6) 1 question the desirability or the near-term possibility of creating a general SDSS. I fear that the need for a multiplicity of geographic functions would overwhelm non technical users just as they are overwhelmed by the complexity of today's GIS packages. (I would really like to be wrong on this point, incidentally!) The closest package I have seen to a general SDSS is Criterion Corp's "Landtrak" system (Ref 6) which is powerful enough to be difficult to use.

I think it will be much more useful and responsive to work on SDSS generators and construct easy-to-use SDSSs that are optimized for particular problems. Examples of two such SDSS applications are outlined in (7) and (8), below.

In many instances, it is possible for an analyst to design a specific SDSS for an application which can then be used in each of over 200 Postal Management Sectional Centers (example 8, below) or in countless redistricting cases (example 7) ranging from congressional districts in a state to school districts in a small city.

7) I find it easiest to think by example, and one application that helped me structure my thoughts on SDSS is that of congressional and legislative redistricting. The goal of redistricting looks simple: produce a tiling of a state into a specified number of compact, contiguous districts in such a way that they have equal or near-equal populations and no racial or political group is systematically disenfranchised.

A technician's immediate reaction is often to treat this as an expert system application -- to the horror of the decision makers. Their aversion to an algorithmic or AI approach to redistricting is based on political reality: an office-holder must live in his/her district; a tacit goal may be to make the next decade difficult for one's political opponents.

Yet even these judgements mustn't be decided by computer -the final decisions may be political compromises to preserve incumbency on both sides. It is apparent that today's political climate cannot tolerate an expert system making such important decisions, nor in the heat of negotiations in a smoke-filled room can one afford the performance overhead of a full-functioned GIS. The middleground -- a specific SDSS -- is the choice many organizations are making as the next redistricting cycle approaches.

8) Another SDSS application I found useful is one proposed to help the US Postal Service make facility decisions as optical scanning and bar-code sorting machinery is introduced.

It's a long story, but briefly: mail for 3 or 4 zip codes (post offices) is often sorted in a single facility for the purpose of delivery distribution. When automated sorting gear is introduced, the same facility may be able to sort mail for five or six zips. On the average, it,may be possible to close one half of the delivery distribution facilities. But which ones? And wait a minute, if we close this facility we lose eight retail windows (for selling stamps and weighing packages). What store-front or consignment arrangements could we make to take up the slack? And if the carriers for this zip pick up the sorted mail at the new facility, it takes so long for them to get out to their routes that they miss the delivery "window". Etc. Etc.

Furthermore, you can bet that the same kind of political considerations that intruded on example (7) will surface if a large number of postal facilities are to be closed down.

9) As an afterthought to (5), the NCGIA Initiative 6 team might find it interesting to study the plethora of macro languages, "map engines" and 4GL's which could be considered to be SDSS Generators of one sort or another.

10) All good lists need ten items.

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1) Goodchild, M.F., 1989. "Geographic Information Systems and Market Research" Papers and Proceedings of Applied Geography Conferences, Vol 12

2) Mapping Science Committee, Board of Earth Sciences and Resources, 1990. "Spatial Data Needs: The Future of the National Mapping Program" National Research Council, National Academy Press, Washington, DC (In part: "The committee recommends that the National Mapping Division increase its activities to provide a larger number of classes of spatial data .... (including) .... census,-.-postal and transportation network data... 11 "It is conceivable that commercial needs for national srdd (spatially related digital data) in transportation and marketing ... will be so significant that if the federal government does not move to create and maintain a comprehensive (continually updated) national data base of such features a consortium of firms will have to create it. No doubt it would then be proprietary, which does not seem in the best national interest .... ")

3) Densham, P.J. and M.P. Armstrong 1988, "Decision Support Systems for Locational Planning", in R. Golledge and H. Timmermans eds., Behavioral Modelling in Geography and Planning, Croom-Helm, London, p 74 ff.

4) Cooke, D. F. and Dawes, B. G. 1987, "The dbmap System", Proceedings, AutoCarto-8, Baltimore

5) Terralogics, Inc., 112 Daniel Webster Highway South, Nashua, NH; their SDSS Generator product is "Terraview"

6) Criterion Corp is now part of Geobased Systems, Raleigh, NC. Geobased recently reduced the price of Landtrak to below $4000.

SPATIAL DECISION SUPPORT SYSTEMS:

SUPPORTING VISUAL INTERACTIVE MODELLING

Prepared for NCGIA Initiative 6 Specialist Meeting
Santa Barbara, March 14th-18th, 1990

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Introduction

My point of departure is that I assume that analytical modelling capabilities must be integrated with database management and graphical display capabilities to solve many complex spatial problems. The four key modules of a spatial decision support system - database management system, analysis module, display and report generators, and a user interface -must function effectively in both "stand-alone" and "cooperative" modes of use. Using location selection problems as a context, I wish to explore some of the relationships between system modules and their consequences for system design and implementation.

Development Paths

One path to developing spatial decision support systems (SDSS) is to supplement an existing GIS by adding an analytical modelling module to its structure. I believe, however, that simply grafting analytical models onto a GIS may prove to be a myopic approach to developing SDSS. To produce an effective system, designers must think about the fundamental purpose and likely modes of use of a SDSS.

To address complex spatial problems, an SDSS must include the following:

1) a database management system (DBMS) that integrates locational, topological and thematic data types to support cartographic display, spatial query and analytical modelling at a variety of spatial scales and geographical extents for a large number of variables;
2) a model-base management system (MBMS) that provides users with flexible and comprehensive modelling and analysis capabilities that are both combined and extended easily (these capabilities must include the ability to calibrate a wide range of models of spatial choice, etc.);
3) a set of graphical and tabular reporting capabilities;
4) a user interface that enables users to interact with the system in an intuitive way;
5) a repository of expert knowledge which users can draw upon for guidance at all stages of the decision-making process; and
6) support for different cognitive styles of decision-making in a variety of decision-making environments and contexts.

Modes of Use

Personal experience suggests that users of SDSS will want to use the capabilities of a SDSS in both a stand-alone fashion (querying the database for the current locations of a set of bank branches) and as cooperative elements in a more complex task (watching the locations of a set of bank branches change on a virtual map as the user modifies the parameters in the model of spatial choice underlying the location of the branches). The latter mode of use is desirable for complex problems when the decision-maker is unsure of the underlying relations between variables and wants to explore the spatial ramifications of particular functional forms and parameter values. Thus, by watching the changes taking place in the modelled system, the user is able to intervene and manipulate the model during its solution. This kind of human-computer interaction effectively melds the analytical (see Ghosh and Rushton, 1987, for example) and the intuitive approaches (see Schneider et al., 1976, for example) to decision-making. It is the kind of human-computer interaction - visual interactive modelling (Hurion, 1986) - that I think must be the goal of SDSS designers.

The demands placed on system software by visual interactive modelling go beyond those currently supported by most GIS. Consider the sequence of events and the degree of interaction of system modules that must occur to support such an approach. I will use the bank branch location problem as an illustrative example. I am currently working with a bank in Buffalo, NY, and the following are the steps that the decision-makers would like to follow in determining the locations of a system of branches:

1) Display a map of current bank locations and evaluate them with respect to a number of performance criteria using some spatial accounting methods and models of spatial choice.

2) Select:

--a data set containing a segmentation analysis of the bank's customer base; and

--a network representation of the study area (this may necessitate “skeletonising" a larger, more detailed network, or aggregating several smaller networks).

3) Calibrate a model of consumer spatial choice that will drive a location-allocation model.

4) Create virtual data sets (demand and candidate strings, etc.) to support the solution of the location-allocation model.

5) Solve the location-allocation model, using graphics to display the changes taking place in the locations of the bank branches and the number and type of customer utilizing each branch. During solution, the decision-makers would like to be able to:

--stop the location-allocation model and take "snapshots" of the location set, model parameters, etc. for later reference; and

--change the parameters of the model and restart the solution process.

6) Generate a set of reports and graphics which evaluate the derived solution and permit the decision-makers to learn about the consequences of their assumptions and preferences for a solution.

7) Run further models, in a similar manner, to examine the effects of other criteria and models of spatial choice.

To support this visual interactive modelling process the SDSS modules must be highly integrated. To facilitate ease-ofuse, the system as a whole must appear to be a "seamless entity" (Armstrong et al., 1986) to the user. The responsiveness of the system is also an issue (Alter, 1980). To participate in the kind of human-computer interaction described above, decisionmakers must perceive the response times of the system to be commensurate with the task being carried out. This does not mean that instantaneous response times are required but that, in Keen's (1983) terms, the system must pass the "turnaround test" and not delay the decision-making process.

System Design Strategies

To design and implement a system that passes the turnaround test for visual interactive modelling, I believe that we will have to look beyond the traditional, serial processing approach to system design. Visual interactive modelling will require highly integrated database, modelling and display capabilities that are working together in real-time. Even for problems of moderate size, the system will have to support modules working in parallel on the problem; only in this way can we expect to provide the user with real-time graphical displays of the model solution process.

Many workstation-based GIS support multi-tasking. This approach permits a pseudo-parallelism that could be used to support visual interactive modelling but the development of parallel processing computers is a more promising alternative that must be investigated. The announcement of the Compaq Systempro, with its dual Intel 80386 or 80486 processors, indicates that machines with parallel architectures are likely-to become pervasive in a wide range of business computing environments. Currently, machines designed around the Inmos Transputer (including the Meiko Surface and Atari Transputer Workstation) and PC and Sun-based add-in boards provide very high throughput using arrays of relatively cheap microprocessors.

Designing a SDSS to exploit a machine's parallel architecture will permit us to dedicate arrays of processors to each module in the system. Moreover, intelligently-designed software will be able dynamically to allocate processors to individual tasks, so that the more computationally-intensive elements of a cooperative task are allocated more processors.

Conclusions

With a few exceptions (see for example, Sandhu and Marble, 1988; Healey and Desa, 1989; Smith et al., 1989), the GIS field has been very slow to examine the potential of parallel architectures. I believe that the development of SDSS supporting visual interactive modelling for complex spatial problems will require the use of parallel architectures. Furthermore, these systems will feature very different user interfaces to current GIS which tend to use the map as the sole medium of information exchange.

Acknowledgements

Some of the ideas in this paper are developed from points arising in discussions with Marc Armstrong about the role of parallel processing in SDSS.

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POSITION PAPER FOR I-6 MEETING

SOME RANDOM(ish) THOUGHTS ON SPATIAL DECISION SUPPORT SYSTEMS

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Like everything else in life, SDSSs can be divided into two types: those that rearrange existing information and those that generate new information. In the former set I include DBMSs and display algorithms - things which merely present data in a different way, one that is presumably more useful in making some spatial decision. One could, for example, throw up a map of income distribution by census tract within an urban area and use this to locate some high order merchandising facility or to target some advertising campaign.

The second type of SDSS is one. in which new information is generated on a system, usually by the application of some model, which can then be used to examine various aspects of the location of facilities. Following the general principle espoused in paragraph one, these systems can be divided into two types depending on the presence/absence of consumer choice. Where consumer choice is absent, one normally encounters varieties of deterministic location-allocation algorithms, covering algorithms and the like. These are of obvious use in locating things such as fire stations, school districts, and sirens to meet some objective function. For example, individuals do not choose to listen to one siren over another. the sole objective in the location-of sirens is to maximize the number of people covered by their noise and so an optimal locational pattern can be obtained rather easily using only data on the location of individuals.

An optimal location can generally be achieved with less certainty when consumer choice is involved because the allocation of individuals to facilities must incorporate some probabilistic framework. Only once this framework has been established and the appropriate model(s) calibrated can an optimal location for a facility be determined. There are, of course, two types of probabilistic allocation frameworks of importance in supporting spatial decisions: those that involve a set of competitors; and those that involve a monopoly. As an example of the former, consider store choice where consumers are choosing between a set of competing retail outlets. We may utilize an SDSS to examine the optimal location of a store or to perform some sort of market analysis of the customer base of an existing store (Fotheringhain, 1988 gives a list of potential uses of store choice models in marketing). In a monopoly situation, the probabilistic framework can be used to predict the likelihood of a person using that facility with the alternative being not to use it. Examples of such situations include the location of a library or non-emergency medical facility.

In the remainder of this position paper, I will restrict my comments to a probabilistic SDSS taken primarily from my interests in spatial choice and spatial interaction modelling and some practical experience in retail locational analysis. I see five areas which could benefit from further research, all of which could produce "deliverables" within the time-frame of the Initiative.

1. The basis for all spatial choice is some type of information processing procedure by individuals. In order to -understand and predict the outcome of a spatial choice process, it is therefore necessary to understand the way in which individuals process svatial information. Most models that we apply: to spatial choice have been developed in an aspatial context and therefore assume a certain form of information-processing that may not apply to the processing of spatial information. We need to explore spatial information processing more carefully (a link to 1-2?) and to develop, if necessary, explicitly spatial choice models rather than simple applying aspatial models to a spatial context. Some examples of the errors involved in our present methodology are given in Fotheringham. (1989) in the context of store choice modelling and market area analysis.

2. A point mentioned by Goodchild (1989) is that very few GISs presently have the capacity to calibrate models, especially spatial interaction/spatial choice models and this situation needs to be rectified if the capabilities of GISs to act as SDSSs are to improve. We need to be able to interface packages such as SIMODEL (Williams and Fotheringham, 1984) with GISs. There are clearly potentially large errors in. applying spatial interaction models with some "generic" set of parameters as is done presently in certain GISs.

3. It would be useful to have a body of research on the practical pros and cons of working with data at various levels. There are at least five levels of data on which we calibrate spatial models:

(i) individual level
(ii) origin-specific, market-segment aggregates
(iii) origin-specific aggregates
(iv) market-segment aggregates
(v) aggregate level

For instance, if we want aggregate level forecasts of sales potential, is it better to calibrate disaggregate models and aggregate or to perform aggregate level analyses? At what level of data are parameter estimates most stable across contexts?

4. Given that spatial choice data are often difficult to obtain, to what extent are the calibration results of various spatial choice/spatial interaction models transferable? Transferability here might mean over space, over time, over different levels of aggregation, and between different population subgroups. The degree to which various models are context-specific needs to be investigated further. If we can achieve models that are relatively robust in terms of calibration (that is, the results of calibrating such models are relatively insensitive to variations in context), then we can be more confident in applying models in situations where we do not sufficient data for calibration (a rather frequent occurrence). The advance of the competing destinations model (Fotheringham, 1986) over more traditional models may be important here.

5. There is a need to link the application of spatial models with GISs. The future of GISs would seem to lie in increasing their analytical capabilities. How best can we improve the performance of GISs by hamassing the power of spatial analytical techniques? Can we improve the performance of spatial models by harnassing the power of a GIS? We might, for instance, expect greater interaction between the user of a GIS and the system under investigation by means such as touching a point on the screen and getting an immediate market analysis for a store located at that point. We might also expect better graphic output * and a merging of GIS capabilities such. as the use of shortest path algorithms in a network for store choice modelling (Goodchild, 1989). However, these seem to be rather marginal improvements in the spatial analytical framework compared -to those that are derived from an increased understanding of the basic relationships within a spatial system and which are more likely to come from outside a GIS framework. Therefore, I feel that the relationship between spatial analysis and GIS is primarily a one-way street although it will be interesting to see if I can be convinced otherwise by this meeting.

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POSITION PAPER

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The concept of a spatial decision support system (SDDS), as used by Densham, Rushton, Goodchild and others, consistent with the general decision support system literature, is useful in setting the stage for the successful application of GIS technology in application domains where traditional GIS packages have not proved appropriate. Among these are two of the focus areas for this meeting: marketing and retailing. By and large, GIS has not made a significant impact in these applications because of the gap between the functionality, ease of use, flexibility and openness of today's GIS products and the requirements for a SDSS. At the same time, isolated highly-focused analytic models have not been well-integrated with corporate database, mapping and interactive analysis resources, thus limiting their application.

As pointed out in Densham. and Goodchild, 1989, the characteristic features of a DSS, as defined by Geoffrion, serve to distinguish GIS from SDSS. The lack of these characteristics is also what limits GIS packages from achieving a full degree of utility as analytic problem-solving tools in areas such as marketing and retailing.

At Spatial Data Sciences we have been, over the past three years, involved almost exclusively in attempting to build primitive spatial decision support systems for limited problem domains. Depending on the particular problem domain, the computing environment, the project budget and time-frame, a mixture of off-the-shelf and custom-developed software has been used. A key design decision that has been faced in each case is what, if any, role can/should an off-the-shelf GIS play in building a comprehensive SDSS? In each application domain within the general areas of marketing and retail planning, the spatial data management, primitive spatial operators, map display, and utility functions provided by most modern GIS products are needed. However, the SDSS builder pays a severe price for the use of the GIS. This price, which may result in such negative effects as a compromised user interface, difficulty in integrating domain-specific analytical tools and models, problems in integrating the SDSS within the general corporate hardware / software / database environment and reduced performance levels due to the computing and memory overhead attributable to the GIS. This price is, in many cases, too steep to pay.

An example of a specific spatial decision support system that we -have developed may illustrate some of these issues. This system deals with the problem domain of sales force management and the related sub-problem of sales territory alignment. For many organizations with large out-of-the-office sales forces, managing and strategically controlling the sales force is a major problem. Companies typically will reallocate sales forces every year, a process which is time-consuming, expensive, controversial and considered to yield results which are highly sub-optimal. In recognition of this, a major pharmaceutical firm has made a significant commitment to the development of a spatial decision support system for sales territory management and alignment, In a limited sense, this problem can be addressed using one or more of the optimization or heuristic algorithms for allocation of areal units (e.g., ZIP Codes) to service locations (i.e., sales offices). However, it was recognized by the company that these tools must be integrated with spatial database management capabilities to handle the large cartographic and attribute databases needed, thematic mapping functions, and interactive tools for territory adjustments.

Given the core of an OR-oriented allocation model (using a heuristic algorithm to generate a range of local optima in a reasonable amount of time on a microcomputer-based workstation), a full spatial decision support system also must include a powerful and easy to use interactive capability for adjusting the allocation based on subjective, complex or qualitative criteria. An integrated thematic (i.e., choropleth, etc.) and relational or object-oriented database is needed to manage the large set of aggregate data including sales results, sales potential, market share, and associated demographic and socioeconomic variates.

In our experience, corporations and other users of decision support systems are unwilling to accept, on faith, the results of analytical decision aids due to the simplifying assumptions and abstractions that are always present using these methods. Therefore, a spatial decision support system must provide analytical tools (e.g., location/ allocation models) based on as realistic conditions as feasible, along with a wide range of tools to aid the analyst in understanding the results, modifying the results, and determining the implications of each new iteration.

For example, the allocation model used in sales territory alignment should be based on realistic travel times between stops and not on Euclidean distance measurements between ZIP Code centroids, as most packages use today, Users should be able to easily set up constraints on such factors as the total amount of change in alignment the client is willing to accept, the sales goals for each salesperson (i.e., not a simplistic equality goal), etc. Finally, rather than presenting a single "best" solution, our experience is that any decision aid should provide a range of solutions representing different trade-off options. For instance, in the trade-off between travel time minimization and the balance of sales opportunity among salespersons, good solutions at different points in the trade-off continuum should be provided.

Of equal or greater importance to the functionality of an SDSS is its ease of use. As pointed out by Densham and Goodchild (1989), following Geoffrion (1983), an SDSS must be easy to use so that sophisticated technology can be accessed via a user-friendly front-end. An important corollary to this is that the vocabulary used in the system must match the language used commonly by workers in the specific problem domain. Thus, nowhere in system menus should GIS or spatial data handling terms such as "polygon overlay", "spatial search", or "generalization" appear, More importantly, scripts for stringing primitive tools together to form a full analytic procedure must be available to users prior to system installation. These scripts should be comprehensive enough to allow users to interact with the system at a very high level: e.g., “perform territory alignment in the way we usually do it". However, user need the flexibility to alter scripts or interrupt them in order to perform "what if" analyses using different tools, trade-off, goals or constraints than “usual".

Given these significant disconnects between the concept of an SDSS and the reality of today's GIS products, the question of the role of GIS packages in building an SDSS is open to debate. Looking ahead, one may ask whether the goal of creating true SDSS's can be best accomplished by extending current GIS technology or by performing software tool integration at a lower level and building a software system very different than today's GISs. This question is particularly germane in reference to business applications such as marketing and siting analysis which have such different characteristics than other spatial data handling applications.

THOUGHTS ON THE DESIGN OF USER INTERFACES FOR SPATIAL DECISION SUPPORT SYSTEMS
Problem #1: Who is the User?

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Position Paper for NCGIA Specialist Meeting on Research Initiative 6
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INTRODUCTORY STATEMENT

One of several goals of SDSS development which should be of primary research interest is the removal of impediments to designing optimal user interface strategies. The approach I have taken thus far is one based firmly upon the human side of the human-computer interaction equation. This approach, which I will call the cognitive approach, assumes a view of the 'user interface' which emanates from the mind of the user, rather than from from data models or structures within the computer cabinet. The cognitive approach to the analysis of human-computer interaction in geographicalIy-oriented systems (GIS, SDSS) is being investigated as part of my dissertation research, funded by a NSF Dissertation Enhancement Grant (March 1990-May 1991).

OVERVIEW

Attention to user interface issues within the DSS, and nascent SDSS, literature is considerable in breadth but is shallow. This is an encouraging sign, overall; the GIS literature is far more negligent in acknowledging the huge gap that exists between user intentions and what the system can actually do (see Gould, 1989). For the most part, the (S)DSS literature has recognized that small improvements to the user interface can propagate meaningful improvement in the character and quality of decisions made using a system.

> "The move to graphical interfaces for operating systems provides an opportunity for system designers to rectify many of these shortcomings [of previous systems], rather than simply incorporating them in overlapping windows and pull-down menus. A move towards more interactive modelling, with two-way communication taking place via the graphical display, will necessitate the development of intuitive interfaces" (Densharn and Goodchild, 1989, 713).

In fact, some authors place primary importance on the user interface, stating that DSS has, fundamentally, two parts:

> "...the human-computer interface (HO), and the decision-aiding algorithms. As far as the DSS user is concerned, the interface is the system. The user never sees inference algorithms, optimization programs, data structures, and all the other procedures that go on inside the computer, so any real 'aiding' that takes place occurs throught the HCI" (Zachary, 1988, 958).

A RESEARCH PROBLEM

I wish to offer for contemplation some good news and bad news. The good news is that most (S)DSS researchers recognize the key role that user interface must play in system design. This consensus may be considered healthy justification for future research in this area. The bad news is that: 1) the concept of 'user interface' differs in both definition and scope among the many fields studying it (psychology, computer science, engineering, cognitive science, others) and is thus difficult to pin down; 2) the nature of the DSS, as prescribed by Gorry and Scott Morton, Sprague, and others, impedes our identification of the 'user', the person(s) for whom we must design an optimal interface to maximize decision-making results. Sprague (1980) describes the roles to be played by individuals involved in DSS development and use--the manager [here, the decision-maker], intermediary, DSS builder, technical supporter, and toolsmith.

> "The intermediary is the person who helps the user, perhaps merely as a clerical assistant to push the buttons of the terminal, or perhaps as a more substantial 'staff assistant' to interact and make suggestions" (1980, 7-8).

This assumes the user to be the decision-maker. He then states:

> "The top two [manager and intermediary] are familiar even in name for the development of many interactive or online systems. It is common practice in some systems to combine them into one 'virtual' user for convenience" (1980, 9).

Thus, a contradiction as to the identity of the user is present even in the early literature. It has propagated throughout recent literature, as seen below.

> "As Ginzberg and Stohr (1981) observed, 'an objective of DSS development is to provide easy-to-use non-procedural languages for both the data and modelling interfaces'--the ultimate being natural language interface (p.14). Many who work in artificial intelligence have the view that natural language is the ideal medium of communication between the decision-maker and the DSS. However, the use of intermediaries means that the interface can be procedural.
>
> ... The major criteria to be met are that the interface lets the users do what they want to do, and that it is relatively easy to communicate these needs to the system" (Densham and Rushton, 1988, 77).

This contradiction is a theoretical impediment to the design of optimized user interfaces for (S)DSS. Just who is the user in our concept of user interface? The decision-maker? The 'intermediary'? Some other actor? For whom do we design the SDSS?

Opposing Arguments

The role of the intermediary in ensuring smooth system operation (and, presumably, better decision making) is one of possible interest to be discussed at the Initiative 6 meeting. On one hand, it may be argued that the intermediary is often an expert analyst (eg., in location-allocation or oil spill response) without whom the decision-maker would waste vast amounts of time due to lack of experience judging the optimality of model parameters and predicting model results. Incorporation of the expert analyst level of intermediary is a strong point to be considered; consideration of lesser levels of intermediary reminds me of the story of the Ford Motor Company executive who, in the 1920s, prognosticated that the world-wide demand for automobiles would peak at 1 million due the lack of qualified chauffeurs!

This leads to the other side of the argument: it may be argued that information systems, even those as complex as GIS or SDSS, are evolving to the point whereby designing for the necessity of a human intermediary seems fruitless. Perhaps the intermediary was of more value in previous decades, when the DSS ran on a massive, arcane mainframe. Do spatial decision-makers really need a system operator, or can we not design SDSS to be usable by the intelligent general public? Supporting the latter position are those who have recently created executive information systems. EIS are being plugged as efficient vehicles for bypassing the MIS department, by allowing information to reside on the decision-maker's desktop in a comprendable format. Whether or not EIS are just hype is not important here. What is important is that information to support complex decisions is now reaching the decision-maker's desk in the form of PC/workstation-based systems. We can choose to ignore this or to design SDSS with this fact in mind.

ONE POSITION ON THIS PROBLEM

Unless we really believe that decision-makers aren't to be trusted to operate computerized systems, we must look beyond reliance on the intermediary, straight to the more complex and difficult task of designing (S)DSS for users who are themselves the decision-makers. An alternative is to design several levels of user interfaces, each level conforming to differing individual cognitive and institutionally-based decision-making characteristics of Sprague's nebulous "virtual" user. The latter seems a rather messy and unmanagable task.

On Software Solutions

In order to replace the human intermediary in the (S)DSS scenario, heavy reliance must be made on user-assistance software. In search of user assistance, it is often matter-of-factly suggested that the addition of expert systems (and recently natural language handling) will somehow metamorphose a computerized system 'human', to be naturally interacted with. However, this cannot be achieved simply by plugging-in prepackaged software. The building of expert systems suitable to represent the knowledge of a seasoned analyst is, to say the least, a formidable task. Ironically, this expert knowledge representation may prove to be the most easily built of the expert systems SDSS will require. Construction of expert systems to handle the liberation of the user's natural thought processes may prove to be far more taxing.

If the complexity of building multiple expert systems to support natural thought processes is ill recognized, then the comprehension of natural language handling is worse still. The current state of natural language handling is that there are many systems (both prototypes and those on the market) which deal with spoken language, so long as the user speaks slowly, in discrete utterances, and does not diverge from a predefined lexicon of 500 or so words; this is not exactly natural. Natural language, as defined by human-to-human discourse standards, is far from implementation in any system. Moreso, a group at Buffalo (Mark, Gould, and Nunes, 1990) has addressed a sample of cross-cultural/cross-linguistic issues in spatial language which will further confound natural language handling for geographically-based information systems. It must be remembered that not all decision-makers speak english, and many of those who do, but are non-native speakers, are likely to be thinking in another language. Thus, a response to naive boasting of including natural language handling into one's information system might be "Great. What natural languages does it handle?" Cora, a language spoken in Northern Mexico, for example, has over 150 individual words to describe variations of the spatial notions "over there" and "over here".

In concluding, it must be stated that I do not advocate dismissal of either expert systems or natural language handling (see Gould, 1989, 548). Rather, the research community should begin preparing for the inevitable evolution of these human-assistance tools by attaining better understanding of the cognitive structure of the human attributes (i.e., spatial language) which are to be supported by these tools. Laboring at the applied task of appending expert systems and other software to today's SDSS should be of lesser scientific priority than the basic research issue of identifying the human cognitive structures to best be represented or supported in these software decision-making aids.

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NCGIA
Initiative # 6

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Rather than contribute further +n your burden of reading, I would like to offer a few simple observations:

1. Michael Goodchild and others have essayed to establish a taxonomy of GIS functions. To speak meaningfully about spatial decision support systems (SDSS) we should also consider a taxonomy of decisions that must be made in a spatial context. Only then is it reasonable to think about the structure of systems that might support these decisions.

2. The current generation of GTS suffers from one over-riding flaw: it denies the autonomy of the user. Popular GIS packages are black boxes. The user interacts with a compiled program, but has little sense of the bits and pieces. The next generation of GIS should be less grandiose, and should give more scope to restructuring. By way of analogy, consider a "black box" statistics program such as SAS versus mathematical reasoning tools such as MathCAD. The latter is much less grandiose but can be restructured according to the user's current line of reasoning. Similar advances are needed in GIS technology if GIS is to become a truly effective component of a SDSS. I will be happy to speak with interested persons about the kinds of applications I have in mind.

3. Technical advances of the type described above will fall on fallow ground unless decision makers have more highly developed spatial reasoning skills. To continue the analogy from above, the relative advantages of a MathCAD package over a SAS package are meaningless if the use cannot reason mathematically. Put another way, the generally poor spatial reasoning ability of end users may be why technical advances have not gone in the direction proposed here. Those of us in the education field must therefore take our responsibility most seriously.

Notes on research issues concerning SDSS February 19, 1990

drawn up for the NCGIA-16 meeting, March 1990 Santa Barbara

Paul Hendriks (NCGIA, Santa Barbara)

The definition of Decision Support Systems[1]

As recognized for instance by Densharn & Rushton (1988) there appears to be a need to explicitly describe the essential features by which a DSS can be defined and by which a DSS can be marked off from other computer systems that may be of help for supporting decisions. What should be avoided is a similar situation as has evolved for instance with expert systems where every system that is in some far fetched way based on knowledge of domain experts is called an expert system. The major reason for looking for a clearcut definition of DSS is that it may function as a skeleton for designing a research agenda for SDSS. But it also expresses the wish to avoid the babel of tongues which seems to prevail in part of the literature on DSS. The following three characteristics of DSS's may be said to lay down the essential features of any DSS, that is they convey the core meaning of the term 'DSS'. In this sense each of the properties is to be considered a necessary condition for a system to be called a DSS. If any of the three is lacking in a system, there still may of course be elements in it that will (eventually) turn out to be of major interest for turning it into a DSS, but it should not be called a DSS. So, a computer system may be said to be a DSS if:

1. it's designed to deal with ill-structured or semi-structured problems;
2. it is based on empirical models, possibly models that interact with one another, and it allows the user of the system access to all things needed to make the models run (data, definition of parameters, output of one model as input for another, and the like);
3. it is user friendly, both in its current stage and in its adaptability to changing demands of the user.

There are definitions, like Geoffrion's, referred to by Densharn & Rushton (1988, p.61), that provide lists longer than the one above. These definitions are both confusing in the sense that they may include a number of features that may be interesting to be included in a DSS, but do not define it, and in the fact that the spreading of items that belong together over a number of points tends to obscure the view of what we should concentrate on when working on DSS's.

Ill-structured and semi-structured problems

Following Bosnian (1983, p.80) we may identify ill-defined problems as those for which any one of the following three properties is lacking:

1. the set of action alternatives is finite and identifiable; lack of this may for instance result from a lack of unambigousness in the DM's objectives[2];
2. the solution is consistently derived from a model that shows a good correspondence;
3. the effectiveness or the efficiency of the action alternatives can be numerically evaluated.

It is not hard to think of situations in which at least one of these conditions of 'well-defined problems' is not met. To give just a few examples: the evaluation of possible scenarios for meeting the electricity demands of a state or a country, including alternatives for locating power plants, given the various types of fuel they may use; the decision where to allow new housing projects to be developed, and to fix the priority as to the type of housing; drawing up a plan for allocating future investments in foreign countries. All these examples relate to strategic decisions, that is decisions setting out a framework for future lines of action. Problems involved in strategic decisions are by definition ill-structured. The standard evaluation techniques (multi criteria evaluation, linear programming techniques, etc.) are of no direct use here because they presume the availability of common dimensions on which the alternatives may be compared (primarily these dimensions will relate to empirical characteristics of -spatial- objects, but one may also for instance think of choice alternatives in terms of the money involved in effecting them). In the case of ill-structured DPs it will be more common that no such common dimensions are at hand than that there are. For instance: location aspects in the case of a coal fired

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[1] In this paper the following abbreviations are used:
DSS = Decision Support System;
SDSS = Spatial Decision Support System;
DM Decision Maker;
DP Decision Problem.

[2] It will be more common in the complex decision problems that are most likely to comprise illdefined problems, that the user of the DSS will not be the same person as the decision maker (DM) himself-, one may presume the presence of a person with a certain amount of domain knowledge who will operate the system to advise the actual DM. Such an intermediary person will be labeled DM in this paper and not distinguished from the person who actually takes the decision.

plant comprise the availability of coal, the nearness of a major see harbor, pollution issues in terms of dust; in the case of nuclear power plants none of these are relevant, one should rather look at things like potential health risks for nearby population concentrates and agricultural activities evacuation costs in case of fall-out.

The first and foremost problem to be solved when developing DSS's therefore is how to get a grip on ill-structured problems. Characteristic for an W-structured problem is the fact that, though some parts of it may be subject to modelling, some of them may well either escape our current state of knowledge or may even escape structuring at all, so the DSS should not treat them as though the opposite were true. That is: the DSS should not be constructed in such a fashion that given a specific DP it will automatically generate an effective solution for it. What it should do is provide the DM with a tool that allows him to play around with the DP he's facing in as many directions as possible. It should not restrict him to the use of a set of predefined solutions generated by the currently available geographical models. It is this seemingly unavoidable contradiction the DSS developer should master: he should introduce a structure into his system that allows a certain degree of unstructuredness in the object. How do we structure the instructurable?

Decision support through logical modelling

What is called for is an approach which, while retaining the possibility of a certain amount of structuring, has an open end in the sense that it allows the DM to introduce the additional knowledge he has on aspects of the DP at hand and to fit it in with the knowledge (for instance in the form of empirical models) already there. Knowledge representation techniques originating from the Al research seem to offer exactly this open end. More specifically: the principles of logical modelling provide formalisations that combine the unambiguousness of any formal structure with the versatility that is called for by the ill-defined decision problems.

Although it is quite conceivable that the goal-state the DM is striving at is itself not clearly defined and it is also conceivable that one may want to make this goal-state itself the object of a DSS, we may presume that a more common situation will be that the goals are to some extent well described, at least to the extent that for some aspects of the goal-state a number of, possibly conflicting objectives, have been formulated. For instance: finding ways of providing a region with adequate electricity supply while restricting pollution and preventing unacceptable risks for the population or for other agricultural or industrial activities. If a, possibly only provisional, description of the desired goal-state is at hand, and if at least part of the way towards this desired goal-state may be subject to decision making (that is: if some manageable constraints are available), than the following framework may help us introduce some structure into the DP: the formulation of it in terms of goal-means-conditions. In a nutshell this approach (described for instance by Vander Smagt & Lucardie, 1989) will take the following form: the goals, purposes or objectives can be regarded as all those more or less independently existing parts of the desired goal-state that may be recognized (supplying electricity, keeping pollution within bounds, limiting hazards). The means for arriving at the various goals, may be identified as the alternative paths that may be followed. The conditions are to be seen as the concrete, empirical properties that real-world objects should have in order to be able to act as means for a given objective. So, for instance, we may set out to give a description of the locational demands of various types of power plants (different sizes, different fuels, different number of plants) which is likely to result in as many sets of conditions as different types of plants are recognized. A comparison of conflicts in the combination of the various condition sets may help to provide insight into the possibilities of aiming at several, possibly competing goals at the same time. As the links between goals means and conditions can be represented in a logical fashion, and as the operations on the resulting sets for finding out where possible areas of conflict are may be defined in logic as well, it will be obvious that logical modelling provides an adequate way of formalizing this approach.

It may be clear that there is a certain amount of relativity involved in this exercise of splitting a DM into goals, means and conditions: what may defined at one level as a means may be defined as a goal on a lower level, and vice versa. So providing the means to reach a specific end may well turn out to be not much more than a displacement of the problem. In this sense, we cannot claim that describing a DP in terms of end and means turns an ill-structured problem into a well-structured problem, it only helps the problem to become less ill-defined. One should, on the other hand, not underestimate the potential gain that may be expected from the proposed structuring. For it allows the designer of the system or the user (the DM) to sort out exactly what is known about the decision problem, and what is not. So it allows him to point the finger at exactly those points where it is possible to call in empirical models for those partial problems for which models are available, and to sort out for which parts of the DM no support can be expected from the DSS given the current state of knowledge.

Implicitly assumed in the previous discussion is the adoption of a two stage approach, as also already suggested by Reitsma (1990): the first stage concerns the construction of the sets of alternatives that given a specific goal or combination of goals may be described as functionally equivalent using the available knowledge described in the rule set. If the first phase comes up with an undesirably great set of alternatives a second phase of reducing this set may be called in. In this second stage one may consider the possibility of using standard evaluation techniques to generate some sort of order among the equivalents. It will be clear that, given the nature of ill-structured problems, the first stage is by far more important than the second. The essence of a DSS should be that it allows the DM to combine all the available knowledge to reach a conclusion by identifying the implications that aiming at several goals at the same time may have. it is in this first stage that the DM should be allowed to perform his simulations, in order to see what implications deliberatley introduced changes in the rule set will have for the generated set of functionally equivalent means and the conditions they point to. This way he may test the sensitivity of the suggested solutions as regards their dependence on these parts of the knowledge base that are more secure and those that are relatively insecure.

Some suggestions for future research

Some research has been done in the field of logical modelling in geography over the last couple of years (see for instance Reitsma, 1990). This research was performed within the framework of the development of specific dedicated DSS's, so the designed tools where also dedicated tools. Attention here has concentrated on exploring a number of alternative schemes for integrating base data and logical representation of rules for the adequate use of these data in the decision context, as well as the introduction of foreign elements, such as dealing with uncertainties. Apart from the theoretical work needed to explore more fully the potentials and limits of logical modelling in geographical research in general and in SDSS in particular, there also is a lot more practical work to be done. In a number of respects the developed representation schemes and their use for decision support are open to improvement, for instance: of central importance seems to be the enhancement of possibilities for the DM to be able to inspect all the rules used by the system in an easy to understand format (experiments have been performed to use decision table format for this) and to allow the DM to alter these rules, to delete parts of them, and to add new rules of his own; some work has been done on sensitivity analysis, but there surely remains a lot of work to be done here; the use of the spatial properties of the data has not been integrated to a great extent (one may for instance be interested in linking the standard spatial functions available in any major GIS with the model outcomes of the DSS); only rudimentary provisions have been developed as to the linking of the two stages mentioned before: formulating the outcomes of a functional matching approach in terms of their suitability as input to evaluation tools and actually using standard geographical models as evaluation tools on the results of the matching.

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Spatial Decision Support Systems

Research Initiative Position Statement

February 19, 1990

Lewis D. Hopkins

Spatial decision support systems involve conversations between humans and computers about spatial problems. Research issues can thus be categorized into three areas:

1. Capabilities of the conversants, at least some of whom are human and some of which are computers

2. Characteristics of problems and of tasks associated with exploring these problems

3. Design, development, and evaluation of decision support systems, considering the performance of the human and computer participants together

Capabilities of Conversants

A great deal is known from psychological research about capabilities of humans as problem solvers. Short term and long term memory limitations, associative memory structures, conservatism biases (e.g. anchoring, confirmation bias), decision making illusions (e.g. Kabneman and Tversky's military strategy problem), and pattern recognition abilities all affect the outcomes of human problem solving. Humans are also the source of values, so systems must always involve bringing such values to bear on the problem. Tools can be provided that complement these abilities, one such tool being additional humans with different experience, which has been shown to yield improved problem solving. To apply Ronald Howard's concept of decision therapy, we must devise ways to know what a decision maker intends and how this differs from what that decision is able to accomplish in actual decisions. Then we can devise decision support tools that not only increase decision making efficiency, but also increase effectiveness,

Compared to humans computers have different memory structures (e.g. less difference between short and long term), more precise operations, and different types of conservatism biases (e.g. inability to associate general knowledge with specific situations). One research opportunity is to take advantage of increased computing power to associate more general knowledge with problem solving procedures designed for a given problem domain. Another opportunity is to design conservatism into computer systems specifically to complement human conservatism biases.

The capabilities of the conversants also set the context for the nature of the conversation between them. The conversation consists of a set of action.s, not a sequence of problem solving steps. One action may serve more than one problem solving purpose at the same time. For "ample, display of a representation of an alternative may confirm feasibility, prompt consideration of new criteria, suggest new alternatives, and communicate among participants. Interfaces should, therefore, support actions in any order, not just provide sequential problem solving procedures. A balance is necessary, however, so that the conversation gets started. A good SDSS should not just he user friendly, but also be a good friend. That means learning from experience and recognizing its conversational partner as a unique individual with different biases, different experience, and different initial abilities.

Characteristics of Problems

Characteristics of given problem domains affect the appropriateness of tools and therefore also set the limits of reliable use of a given system.

The most crucial element is representation because it affects conservatism bias and search efficiency. It is almost certain that multiple representations, both for human and machine, are desirable, but we have very little research to confirm this. Such research should focus on discovering in what ways representations should differ and how to create such different representations in partially systematic ways. These results will be highly problem specific and thus depend on the characteristics of problems in the chosen domain. Spatial problems provide excellent cases to begin investigating the more general question because they are readily susceptible to graphic as well as symbolic representations.

Evaluation of Systems

Evaluations of systems are a major research need. Imagine the pressure on our research if the Food and Drug Administration regulations applied to SDSS so that we not only had to prove that a system providing decision therapy was safe, but also that it was effective. Decision support systems inherently apply to incompletely defined problems. They should thus be evaluated in use because effectiveness of the computer component and the human component are interdependent and cannot be tested alone. This requires construction of prototypical systems for particular problem domains so as to test general principles of system design that can then be applied with confidence within the given domain. Experimental, designs to evaluate SDSS's for incompletely defined problems have been devised, but very few systems elements have been evaluated in this way. One such experimental design is to devise a system and choose a problem so that after using it subjects are likely to agree on what is a good solution; then give two sets of subjects SDSS's with different elements and have all subjects judge outcomes from both sets. A second experimental design relies on mutual anchoring effects of two techniques so that one subject can apply two techniques and interactively generate a neutral standard of comparison.

Summary of Research Opportunities

On capabilities of conversants:

1. What decision making biases or illusions (either human or computer) occur in specific spatial problem domains, such as location-allocation problems, and how are these related to particular representations?

2. What balance of prompted sequential procedure and arbitrary choice of actions is most effective and efficient?

3. How should an SDSS be designed so as to become good friends to multiple users?

On characteristics of problerns:

1. What constitutes a reasonable domain for a problem centered SDSS as opposed to the data-centered generic GIS? How can we estimate reasonable domains in order to design systems that are not narrowminded within a given domain?

2. What types of differences among representations are effective in countering biases and achieving search efficiencies and how can such representations be generated in partially systematic ways?

On evaluation of systems:

1. What experimental designs are most effective and efficient for evaluating SDSS's?

2. What properties of SDSS's can be shown to be beneficial across a broad scope of problem domains so that experimental results can be generalized as a basis for SDSS design principles?

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A Model Management Approach to Analytical Modeling in Geoprocessing systems

In the currently existing geographic information systems (GIS) the emphasis is on data selection, aggregation, analysis, and output (Cowen, 1988). The analytical modeling capabilities encompass cartographic modeling facilitated by the overlay technique and spatial analysis operations. Some of the more sophisticated GIS also incorporate the optimization function for a certain, limited range of problems (e.g. a network problem). They fall short, however, of displaying modeling and simulation capabilities demonstrated by mathematical models of, for example, physical and socioeconomic processes and systems. This lack of more sophisticated modeling capabilities leads to the failure of current GIS to fulfill their potential as decision support systems (Birkin et al. 1987). In that context the concept of a spatial decision support system (SDSS) has been proposed as the formula for amending the decision-making support capabilities of GIS (Armstrong et al. 1986)

In our view the task of expanding the analytical modeling capabilities of GIS is to a large degree synonymous with the problem of incorporating analytical models in SDSS, and it can be solved by addressing two problems:

1) what is a suitable approach for representing analytical models of physical and socioeconomic processes and systems in a SDSS or GIS, and
2) how can analytical models be manipulated (retrieval, model coupling) and subsequently integrated with a geoprocessing system.

The framework proposed for solving these problems is modelbased management system. Conceptually, a model-based management system facilitates storing atomic elements (model building blocks), their retrieval, and recombination into the structure comprising a coupled, case-specific analytical model (Jankowski, 1989). The atomic elements can be perceived as models that are not further decomposed. They can take a form of objects or discrete modules of code that can be reused each time a new case-specific model is generated by a model-based management system. The model generation is accomplished by following the atomic element recombination rules that can be stored as modeling knowledge.

Such an approach departs from the concept of incorporating analytical models in geoprocessing systems by storing the libraries of analytical subroutines. The subroutines have to be configured by a user to become case-specific models, their combination into coupled models can be cumbersome, and they are wasteful in terms of replicating code (Densham and Goodchild, 1989).

We surveyed three approaches for model representation and manipulation that can facilitate the design and implementation of a model-based management system:

- Entity-Relationship approach to model representation (Blanning, 1986),
- Structured Modeling (Geoffrion, 1987), and
- System Entity Structure/Model Base (Zeigler, 1987).

Two of these approaches, in our view, i.e., Structured Modeling and System Entity Structure/Model Base can be applied to a hierarchical, modular model specification which we consider as proper for generating analytical models of physical and socioeconomic systems.

A prototype of a model-based management system for storing, rule-directed generation, and simulation of simple water quality models was designed and implemented using the System Entity Structure/Model Base approach (Jankowski, 1989). Although the prototype was not linked with a data base and graphic display the research provided a testbed for using the System Entity Structure/Model Base as a generative model representation scheme for storing, retrieving and manipulation of atomic elements. our research interest is now directed at:

- using the System Entity Structure/Model Base approach for other modeling domains that are of significance to SDSS and GIS,
- linking the model-based management system with the traditional modules (data base, and graphic display) of a geoprocessing system.

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ON THE PHILOSOPHY OF GEOGRAPHIC DECISION SUPPORT SYSTEMS

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INTRODUCTION

Computers are not taking over the world. However, people with computers are. Our watches, automobiles, and kitchen appliances have all become computer based. So have children's toys, and soldiers weapons. The map, a geographic tool that has withstood the ages has also been changed by high technology. The birth of Digital Cartography, Geographic Information Systems, and Automated Mapping/Facilities Management resulted from the fusion of geographic and computer training. As geographers, it is not enough to ponder the creation of faster and smarter technology. Rather, we must also apply our understanding of geographic processes to clarify the roles our machines play in human affairs.

This paper will analyse a hypothetical geographic decision support system, the Geographic Information Appliance from three geographical philosophies: Humanism, Positivism, and Structuralism.

INFORMATION APPLIANCE

A technology is good, Adam Smith tells us, if it can "produce the end to which it was intended." In order to do this a technology must be usable. In order to make the benefits of the technology easily available to everyone a computer must be easy and fun. Jef Raskin, Macintosh project creator, formulated the notion of the "Information Appliance" in order to create a system "that makes people happier." Raskin believes that happiness is related to habit (Lammers, 1986):

> "What makes people form habits? When I'm using a system, I'm happiest if I can keep my mind on what I'm trying to do, rather than on the system itself. The system should not intrude.... I wanted my system to be so simple it would not distract users from their main task; I wanted using my system to be natural, like a habit."

He instructs,

> "Habit is something that you do the same way repeatedly, and that you're likely to do the same way again. There are some immediate implications from this.... A system should be "modeless". The same user action should always have the same effect."

This is important because,

> "Whenever there's more than one way to do something, there's that moment of hesitation while you think about the manual. Even after you've developed a habit, sometimes you're doing some work and think, "Gee isn't there a faster way?"

Therefore, Raskin concludes,

> "So not only should one action do only one thing, there should be only one path to a particular goal. That way you always use it, and you never have to think about it. We call that 'monotony'."

So, an Information Appliance is monotonous. It does not slow down nor interfere with user's thought patterns. Rather, it assists by providing information as it is needed. Information appliances can speed thinking, theoretically making possible a happy computer user.

GEOGRAPHIC INFORMATION APPLIANCE

The notion of a simple and quick way of viewing information can be extended to the domain of maps. A Geographic Information Appliance might be useful for providing users with easy access to spatial information concerning a big city such as New York.

Such an appliance could be modeled after NYC ACCESS, a guide to New York City by Richard Saul Wurman (Wurman, 1983). The geographic information displays of the Appliance would be "built the same way a city is built - a fabric, where restaurants are next to shops that are next to hotels, next to museums, next to parks, everything mixed up by type of use, but very much in order.. according to location and proximity to each other."

Wurman's ideas suggest that as a guide to a city, the Geographic Information Appliance should be "organized on the paradigm of browsing." When users search for a particular shop, restaurant, or institution they should come away with a discovery of some museum, park or artifact in the same neighborhood. A little-known fact about the neighborhood, he believes, might also be appreciated.

The appliance might include information on subjects often found within telephone company Yellow Pages. Some interesting subjects found in the New York Yellow Pages (NYNEX, 1987) include:

- History of Manhattan
- Manhattan Communities
- Getting Around Manhattan
- Manhattan Bus Routes
- Subway Routes
- Points of Interest & Things to do for Free
- The Parks of Manhattan
- Shopping in Manhattan
- Nightlife
- New York City Theaters
- Sports and Concert Halls
- Manhattan Events
- Dining Out
- Zip Code Map
- Area Code Map

By placing the focus on one of the potential subject areas we can identify a set of information requirements. Dining Out is a popular activity that can serve as an example. We realize that in order to distinguish among restaurants the user is interested in:

- Type
- Quality
- Expense Atmosphere Specialties Location Hours Reservations Mode of payment

Transportation routing to restaurants and other places is an example of a type of analysis the Geographic Information Appliance might provide. In order to accomplish this, the Appliance might require the user to provide the following information:

- Where are you?
- Where do you want to go? (one or many places)
- What are your constraints? (time, money, number of passengers, scenic or direct route)

The results of an automated route analysis might include:

- Route(verbal directions or highlighted map display)
- Time trip would take
- Cost of trip
- Other information(including parking availability)

PHILOSOPHICAL VIEWS ON A GEOGRAPHIC INFORMATION APPLIANCE

Although we are interested primarily in philosophical considerations of the Geographic Appliance, it is interesting to touch upon the esthetics of the underlying technology. Although it is rare, a computer program can be viewed as art. A beautiful program does a job elegantly with a simple structure. Esthetic qualities rely upon intrinsic properties of a computer program. Gary Kildall describes aesthetical aspects of programming:

> "When a program is clean and neat, nicely structured, and consistent, it can be beautiful. I guess I wouldn't compare a program with the Mona Lisa, but it does have a simplicity and elegance that's quite handsome. Stylistic distinctions of

different programs are intriguing, very much like the differences art critics might see between Leonardo's Mona Lisa and a Van Gogh."

HUMANISM

Humanism is a philosophical approach that "emphasizes distinctively human ideas, interests, and values. A humanistic geographer might be interested in understanding a technology's effects on daily activities of spatial decision makers. If a Geographic Information Appliance is used chronically to- save time in transit the user might wind up with more time on their hands then they know what to do with. They might miss out on routes that are longer, but provide scenic vistas or pass up the opportunity to enjoy architectural or other enjoyable places. If this were the case the humanistic geographer could point out to the appliance's designers that the criteria used within automated route selection is not useful to those who are in no rush to get to their destination. The geographer might suggest that people are often interested in visiting scenic places and the routing options should reflect this.

Perhaps, quality of life is degraded by routes that take travelers through economically depressed areas normally avoided by decision makers. Economically depressed areas are often avoided for many reasons by more affluent people. Even among poor residents there is an understanding of dangerous regions that are to be avoided. A Geographic Information Appliance whose design neglected this fact would rapidly fall into disuse as its routes continued to insult the sensitivities and endanger the lives of the traveler. Therefore avoidance of impoverished and dangerous areas might be considered within the routing option. So a favorable route might not always be to find me the shortest route. A favorable route might be one that conserves time and intersects with interesting and beautiful places while avoiding disagreeable sites.

Of course, to be successful such shortcomings and necessary redesigns should be ferreted out prior to an autopsy for a system that failed'. If it is to be a success, the Geographic Appliance must do for spatial decision makers what they wish it to do. Humanist geographers are best in position to evaluate what different groups of people value when making spatial choices. Most importantly, such geographers can aid appliance designers in understanding what kinds values underlie spatial decision making. Incorporating human values into a spatial decision aid increases its utility and consequent happiness of the user.

POSITIVISM

Positivism is a philosophy that "limits knowledge to facts that can be observed and to the relationships between these facts." A positivist might have two perspectives upon uses of a Geographic Information Appliance. If it is equipped with a set of tools for spatial decision making, the positivist might ask: Can we predict which ones are used in various circumstances? Therefore the positivist attempt to study the behavior of spatial decision makers scientifically.

The scientific study of spatial decision making focuses on which spatial decision techniques are used under various conditions. This could be accomplished in the following way. First, a hypothesis is formulated: That is, if the situation is X, the user of the Appliance will perform analysis Y to aid in spatial decision making. That is, the subject can be put in a particular situation that requires change in location from start to destination. The subject is allowed to select routing from start to destination in ways that: minimize economic expense, minimize or maximize elapsed travel time, avoidance and inclusion of various types of places. The experimenter repeats the experiment to determine if any relationships exist between situations and selected spatial analyses.

If the geographic appliance were in mass use outside the laboratory it would be much more difficult to establish situation/spatial analysis relationships. However, questioneers, interviews, and automatic logging within the appliance of types of analyses carried out could serve as a source of data on how people do actually use automated spatial decision making aids, if they are used at all.

STRUCTURALISM

Structuralist philosophies of Radicalism and Marxism would consider how information technology preserves the status quo and encourages interpersonal relationships of economic exploitation. Marxist thinkers might view the Geographic Appliance as just another consumer good created to seduce and distract people from understanding causes of human suffering. On the other hand, it might be viewed as an agent of consumption. The Appliance might be seen as making consumption more efficient and enjoyable and hence encourages complacency with the status quo. The Appliance, geared toward optimum routing while conserving time and money, might be viewed as an evil device that encourages efficient consumption and distracts from the increasing powers of international capitalism and its power to control the world's people. Especially vile to structuralist geographers would be the routing of travelers to avoid distastefully poor and dangerous areas while intersecting with interesting places.

Structuralists might move beyond condemning the Geographic Information Appliance and address its re-engineering. Such re- engineering would be concerned with providing thoughtful citizens with an aid to understanding and subsequently undoing exploitation in the hope of creating a equitable and moral world. This might be accomplished by focusing on spatial relations between social processes and the natural environment. This is important because "social revolutionary changes are necessary to solve endemic spatial and environmental problems, for these problems originate deep in the capitalist social formations"(Harvey and Holly, 1981).

CONCLUSION

As geographers create faster and smarter technology it is important to spend some time clarifying the roles our technologies play in human affairs. The issue of good technology was discussed by Jef Raskin's conceptualization of an 'Information Appliance'. A hypothetical geographic technology, in the form of a Geographic Information Appliance, was described. Its utility within the problem domain of route selection was addressed by the three philosophies: Humanism, Positivism, and Structuralism. By combining Humanistic, Positivistic, and Marxist approaches geographers can gain a well rounded understanding of the implications new information technologies have for the affairs of spatial decision makers.

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Position Statement for NCGIA Specialists Meeting, Initiative Six -Spatial Decision Support Systems, Santa Barbara, March 14-18, 1990

E. Bruce MacDougall

My general area of expertise as it pertains to this meeting is the application of geographic information systems and appropriate models to land use decisions. Some topics of specific personal interest are as follows:

• regulatory responsibilities of public agencies, particularly at the local level (zoning, permitting, project review)

• GIS technology in the assessment of environmental impacts and incremental infrastructure load from proposed land use changes

• methods that assist in planning the spatial arrangement of land uses, in particular the layout of large residential subdivisions

• potential integration of AHP (Analytical Hierarchy Process) and GIS in layout and review decisions

• factors involved in the adoption and use of GIS technology at the local level

• the role and influence of presentation and general characteristics of the user interface in the land use planning process

With reference to the articles distributed with the invitation, am a strong and enthusiastic supporter of the ideas imbedded in spatial decision support systems, and somewhat skeptical of the general utility and practicality of expert systems for land use decisions other than a small number of very specific tasks.

My personal view of a research agenda is that it should be organized around the three areas of data exploration, plan generation, and plan evaluation, all as they result in land use decisions that accelerate, improve (i.e., result in less costly solutions), or enhance (i.e., result in more novel or creative solutions) conventional decision processes.

Expressed in matrix form:

	accelerate	improve	enhance
data exploration			
plan generation			
plan evaluation			

Two of several reasons for proposing this view of research needs are:

(1) it is consistent with (and supported by) current views of dealing with numerical data (in particular for data exploration);

(2) it explicitly recognizes the desirability of novel or creative solutions (to avoid being caught in the trap of reinforcing the mediocre).

On the personal side, I was first involved with GIS issues at the University of Toronto around 1964, wrote a Ph.D. dissertation that used computer mapping in 1967, continued with the field on the faculty of the University of Pennsylvania (including a book: Computer Programming for Spatial Problems, London: Edward Arnold). In 1977, however, I became a department head at the University of Massachusetts, and in 1984, became Dean of the ag college. In 1989, 1 came back to the real world.

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N.C.G.I.A. Specialist Meeting

Spatial Decision Support Systems

March 14-18, 1990
Santa Barbara California

Position Paper

by
Giulio Maffini
TYDAC Technologies

The term Spatial Decision Support System is a useful label which we can use to help focus our technical discussions. We should not, however, let this label confuse our objectives. In my view, Spatial Decision Support Systems should not be a generic stand-alone type of tool, rather it should be a pursuit to discover how the spatial dimension can become an integral part of a more general decision support systems discipline.

In order for the spatial dimension to be integrated into general decision support system it is necessary for us to develop a systems theory which is capable of coping, with the special methodological issues of geographic models. For example, how can different ways of representing geographic data, vector and raster, be reflected in both the measurement and definition of systems.

How will decision support systems be built? Clearly in some cases models can be prescribed to replicate well defined procedures to provide guidance to action. This, however, assumes that the decision making structure is well understood and defined. In my view a more important dimension of spatial decision support is developing models that don't merely parrot what we already know but help to find new structures from geographically referenced information.

Spatial Decision Support Systems should therefore be capable of inferring causal relations between geographically referenced data. The scientific method provides us with a variety of tools for establishing causal relationships. The most well understood is the use of the experimental design method. With it, we can isolate the effects of independent variables and make causal inferences fairly reliably. While in principle there is nothing to stop us from using this approach in building spatial decision support systems, the reality is that most geographic information is observational data collected from many different sources for a variety of different purposes. Thus it is likely that we will require a sound non-experimental method for building spatial relationships.

The Spatial Decision Support Systems must also be able to cope with woolly data that is often qualitative in nature. In addition, the widespread use of class versus metric measures need also to be incorporated. All of this puts Spatial Decision Support Systems at the forefront of some of the more difficult methodological issues encountered by social scientists, economists, and environmental scientists. There is probably a great deal that spatial decision support systems can learn from these other disciplines.

Once models have been ' constructed they can be incorporated into Spatial Decision Support Systems. Other methods are required to validate the appropriateness of these models for the task for which they were intended. Should the models be deterministic, probabilistic, how should they be subjected to sensitivity testing to determine the robustness of the systems to variations in input parameters?

The assessment of whether a model is appropriate for the task implies a very clear statement of purpose which is subsequently used to derive criteria for measuring performance. Spatial Decision Support Systems must draw from a mature methodological framework which will guide developers in building these systems.

The final stage that needs to be dealt with is the building of front ends that will enable the targeted users to easily interact with the structure of the system- The actual mechanics of building the front ends is, I believe, a relatively simple technical issue. What is required is better understanding of the mechanics of interaction between the decision maker and the support system. Experience of how interfaces perform in real time situations is quite thin at this stage. A way of collecting this experience and using it to build appropriate rules of thumb that can become industry standards will be important.

In conclusion, I believe that the objective of spatial decision support should be to integrate spatial methods into already developed disciplines rather than to pursue creation of yet another independent specialist application.

In order for spatial decision support systems to be constructed, the tools should be there which allow us to derive structural knowledge from. spatial data that can be reflected in the models which we build.

Finally, we need to maintain and organize information on the performance of different types of user interfaces appropriate to spatial decision support systems.

DYNAMIC INTERACTIVE NETWORK ANALYSIS SYSTEM (DINAS)

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DINAS is an interactive decision support system that has been designed to assist decision-makers in tackling various location-allocation planning problems (see Ogryczak, *et al.* 1988). The system has been used to solve several hypothetical and real-life spatial planning problems (Malczewski and Ogryczak, 1990; Massam and Malczewski, 1990).

DINAS is based on the reference point approach to the multiobjective decision-making problem. This problem can be written in the following general form:

$$\textit{optimize } \mathbf{q}.$$
$$s.t.\ \mathbf{q} = \mathbf{F}(\mathbf{x}, \mathbf{y})$$
$$(\mathbf{x}, \mathbf{y}) \in Q$$

q represents the achievement vector,

$\mathbf{F}=(F_1, \dots, F_k)$ represents the vector of k objective functions,

Q denotes the feasible set of the program,

x is a vector of continuous decision variables,

y is a vector of discrete decision variables.

DINAS solves this problem in two phases. In the first stage the decision-maker is provided with some initial information which gives him an overview of the problem. The initial information is generated by optimization of all the objectives separately. More precisely, the following single-objective programs are solved:

$$\textit{optimize } \{F_p(\mathbf{x},\mathbf{y}) + 1/k \sum_{i=1}^{k} \varrho_i F_i(\mathbf{x},\mathbf{y}) \ : \ (\mathbf{x},\mathbf{y}) \in Q\} \qquad p=1,2,\dots,k$$

where F_i denotes the i-th objective function and ϱ_i are arbitrary small numbers (positive if the corresponding objective function F_i is to be minimized and negative otherwise). As a result, the pay-off matrix is obtaind. This matrix provides the basis for the identification of reference vectors, i.e. the ideal vector ($\mathbf{f}^i$) and the nadir vector ($\mathbf{f}^n$). The former represents the best values of each objective considered separately, while the latter represents the worst values for each objective function.

In the second stage an interactive selection of efficient solutions is performed. The decision-maker controls the selection by two vector-parameters: his aspiration level $\mathbf{q}^a$ and his reservation level $\mathbf{q}^r$. Both of them should take values between the utopia point $\mathbf{q}^i$ and the nadir point $\mathbf{q}^n$. DINAS searches for the satisfying solution while using an achievement scalarizing function as the criterion in the single-objective optimization. Namely, the support system computes the optimal solution to the following problem:

$$\begin{aligned} & \textit{minimize} && \max_{1 \le p \le k} u_p(\mathbf{q},\mathbf{q}^a,\mathbf{q}^r) + \varrho/k \sum_{p=1}^{k} u_p(\mathbf{q},\mathbf{q}^a,\mathbf{q}^r) \\ & \textit{s.t.} && \mathbf{q} = \mathbf{F}(\mathbf{x},\mathbf{y}) \\ & && (\mathbf{x},\mathbf{y}) \in Q \end{aligned}$$

where ϱ is an arbitrary small number and u_p is a function which measures the deviation of results from the decision-maker's expectations with respect to the p-th objective, depending on a given aspiration level $\mathbf{q}^a$ and a reservation level $\mathbf{q}^r$.

The computed solution is an efficient (Pareto-optimal) solution to the original multiobjective model. It is presented to the decision-maker as a current solution. The decision-maker is asked whether he finds this solution satisfactory or not. If the decision-maker does not accept the current solution he has to enter new aspiration and/or reservation levels for some objectives. Depending on this new information supplied by the decision-maker a new efficient solution is computed and presented as a current solution. The process is repeated as long as the decision-maker needs.

The function $u_p(\mathbf{q},\mathbf{q}^a,\mathbf{q}^r)$ is a strictly monotone function of the achievement vector $\mathbf{q}$ with value $u_p=0$ if $\mathbf{q}=\mathbf{q}^a$ and $u_p=1$ if $\mathbf{q}=\mathbf{q}^r$. In our approach, we use a piece-wise linear function u_p defined as follows:

$$u_p(\mathbf{q},\mathbf{q}^a,\mathbf{q}^r)=\begin{cases} -a_p\,|q_p-q_p^a|/|q_p^r-q_p^a|\,, & \text{if } q_p \text{ is better than } q_p^a \\ |q_p-q_p^a|/|q_p^r-q_p^a|, & \text{if } q_p \text{ is between } q_p^a \text{ and } q_p^r \\ b_p\,|q_p-q_p^r|/|q_p^r-q_p^a|+1, & \text{if } q_p \text{ is worst than } q_p^r \end{cases}$$

where a_p and b_p ($p = 1,2,\ldots,k$) are given positive parameters. Provided that the parameters a_p and b_p satisfy inequalities: $a_p<1$ and $b_p>1$ the achievement functions u_p are convex and thereby they can be modeled via the linear programming methodology.

DINAS consists of three programs prepared in the C programming language: a solver for single-objective problems, a network editor for input data and results examination, and an interactive procedure for efficient solutions generation.

A special solver (TRANSLOC) has been prepared to provide the multiobjective analysis procedure with solutions to single -objective problems. The solver is hidden from the user but it is the most important part of the DINAS system. It is a numerical kernel of the system which generates efficient solutions.

DINAS is provided with the built-in network editor EDINET. EDINET is a full-screen editor specifically designed for input and to edit data of the generalized network model. The essence of the EDINET concept is a dynamic movement from some current node to its neighboring nodes, and vice versa, according to the network structure. The input data are inserted by a special mechanism of windows while visiting several nodes. Independently, a list of the nodes in the alphabetic order and a graphic scheme of the network is available at any time. A window is also used for defining objective functions.

Operations available in the DINAS interactive procedure are partitioned into three groups and corresponding three branches of the main menu: **PROCESS, SOLUTION** and **ANALYSIS**. The **PROCESS** branch contains basic operations connected with processing the multiobjective problem and the generation of efficient solutions. Included are operations such as editing and converting the problem, computation of the pay-off matrix, and finally, generation of a sequence of efficient solutions depending on the aspiration and reservation levels.

The **SOLUTION** branch contains additional operations connected with the current solution. The decision-maker can examine in details the current solution using the network editor or analyze only short characteristics such as objective values and selected locations. Values of the objective functions are presented in three ways: as a standard table, as bars in the aspiration/reservation scale and as bars in the utopia/nadir scale.

The **ANALYSIS** branch collects commands connected with operations on the solution base. The main command **COMPARE** allows the decision-maker to perform a comparison of all the efficient solutions from the solution base or of some subset of them.

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Position Paper for the Specialist Meeting

NCGIA Research Initiative #6: "Spatial Decision Support Systems"

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(My “position" at this Specialist Meeting is mainly one of observer. As co-Leader of NCGIA Research Initiatives #2 ("Languages of Spatial Relations") and #13 ("User Interfaces for GIS"), I will be concentrating on issues related to user interfaces and to the conceptual bases of data models for SDSS. This paper will raise just a few of those issues.)

Understanding Computers and Cognition

"Understanding Computers and Cognition" is the title of a recent book by Terry Winograd and Fernando Flores[1]. In it, the authors raise issues that are central to user interfaces and to decision support systems (DSS). By the title of the book, the relation to DSS may be surprising; indeed, one of the main points of the book is to attack the so-call "strong-AI" (Artificial Intelligence) position that there is in principle no limit to the degree to which computers can replicate intelligent behavior, a topic more closely related to Initiative 2. But, whether or not one agrees with that conclusion, the book is a wealth of information and opinions on the role of computers in society, on the relations between computers and their users, and on design criteria for enhancing the efficacy of such user-computer relations. The book is especially interesting because of the authors' backgrounds: Winograd, a professor of Computer Science at Stanford University, was one of the founders of AI, and in particular of natural language processing, and Flores, now president of an educational corporation and chairman of a software development company, was a cabinet minister in the government of Chile under Salvador Allende.

Design: "What do people do?"

The book is divided into three major Parts: I: Theoretical Background; II: Computers, Thought, and Language; and III: Design. It is this latter "Design" part that deals explicitly with decision-support systems. Underlying the design section are the questions "What can people do with computers?", and the even more fundamental question "What do people do?" Can anyone here answer the question:

"What do spatial analysts (or spatial decision-makers) do?"

for any set of spatial analytic or decision-making tasks and situations? We might do well to try to answer this in one or more working groups during this meeting.

Winograd and Flores state that the terms "decision-maker" and "decision support" already present a narrow or perhaps inappropriate view of problems in management:

> "The managers (and by extension, other workers) we describe might be called decision makers, but that term carries a particular preunderstanding of what such a person does. We want to challenge that understanding." (W&F, p. 144).

In the section that explicitly discusses decision support systems (pp. 152-157), Winograd and Flores present "some of the dangers that potentially attend their use" (p. 153); headings and selected portions of their discussion are presented here:

> **"Orientation to choosing**. The phase 'decision support' carries with it a particular orientation to what the manager does--one that we [W&F] have been criticizing . ...
>
> **Assumption of relevance**. Once a computer system has been installed, it is difficult to avoid the assumption that the things it can deal with are the most relevant things for the manager's concern.
>
> **Unintended transfer of power**… … in [a] sense, ... computer programmers, the designers of computer equipment, and the developers of computer languages possess power . ... Often those who are invisibly empowered have an overall orientation not shared by others within the organization . ...

[1] Winograd, T., and Flores, F., 1986. Understanding Computers and Cognition. Reading, Mass: Addison-Wesley.

Unanticipated effects. Every technological advance brings with it unanticipated effects, some desirable and some undesirable . ...

Obscuring responsibility. Once a computer system is designed and in place, it tends to be treated as an independent entity . ... Once we recognize the machine as an intermediary, it becomes clear that the commitment inherent in the use of language is made by those who produce the system. In the absence of this perspective it becomes all too easy to make the dangerous mistake of interpreting the machine as making commitments, thereby concealing the source of responsibility for what it does.[1] ... ...

False belief in objectivity. One immediate consequence of concealing commitment is an illusion of objectivity.[2] ... ...

To conclude, we [W&F] see decision support systems, like all computer-based systems, as offering a potential for new kinds of human action. With this potential come particular blindness and dangers. The question is not whether such systems are good or bad, but how our understanding and use of them determines what we do and what we are. (Winograd and Flores, pp. 152-157).

Food for thought.

In their last chapter, Winograd and Flores give a "Design Example" (pp. 167-174). The subsection headings, presented here as bulleted text, provide a summary of their approach:

- There are no clear problems to be solved: Action needs to be taken in a situation of irresolution.
- A business (like any organization) is constituted as a network of recurrent conversations.
- Conversations are linked in regular patterns of triggering and breakdown.
- In creating tools we are designing new conversations and connections.
- Design includes the generation of new possibilities.
- Domains are generated by the space of potential breakdown and action.
- Breakdown is an interpretation- everything exists as interpretation within a background.
- Domains of anticipation are incomplete.
- Computers are a tool for conducting the network of conversations.
- Innovations have their own domains of breakdown.
- Design is always already happening.

I hope that this brief exposition, filtered by my own interests and orientation as well as the topic of this Research Initiative, will draw attention to some issues that might otherwise have escaped this Specialist Meeting. I also hope that it will inspire at least some of you to read Winograd and Flores' very interesting and challenging work.

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[1] Issues of responsibility, legal or general, are important to the "fifth bullet" of the NCGIA's over-all research objectives. If Winograd and Flores' book had been written more recently, they might have examined the incident in which the USS Vincennes shot down an Iranian airliner, based on 'advice' of a computer system (a decision support system?), in this context.

[2] Redistricting, including objective functions for creating or avoiding gerrymandering, would form an excellent topic for exploring this aspect of 'objectivity'.

Spatial Decision Support Systems

Position Paper for the NCGIA 1-6 Specialist Meeting
Santa, Barbara, Ca. March 14 - 18, 1990

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Several definitions and assumptions contained in the materials, distributed for the specialist meeting are paraphrased as follows:

> A decision support system is a computer-based information system used to support decision-making where it is not possible for an automated system to perform the entire decision process. That is, it is used to solve problems where no automatic algorithms exist.
>
> The key modules of a decision support system are a database management system, analytical modeling capabilities and analysis procedures, display and report generators, and a user interface.
>
> Those parts of a decision which can be analytically evaluated may be handled by a series of automated capabilities within the DSS. The intangible factors in the decision making process may be accounted for through information supplied and choices made by a decision maker who operates the DSS interactively or operates it through an analyst.

These and similar statements suggest that spatial decision support systems (or at least DSS generators) may be developed as general purpose tools for decision making. Such hardware/software systems presumably would be purchased by potential users (e.g. marketing managers) in much the same way users currently buy word processing software, GIS software/hardware/database packages, or other computer-based capabilities for in house use.

What are the critical underlying research questions currently impeding the full development and the rate of development of DSS? We may assume that a major thrust of I-6 will not be to develop one or more integrated software/hardware systems for which the underlying theory of the various components already exists. That is best left to the private sector although critical foundation knowledge which is lacking and is impeding the ability of the private sector to move forward in the development of useful and operational DSS is appropriate for investigation under this initiative.

Although the pre-conference material includes some discussion of needs of users and the institutional frameworks within which potential DSS users operate, statements on research needs seem to point primarily toward technical issues rather than social or institutional issues and thus technical issues will be the primary focus of the initiative research agenda. The presumption seems to be that a generic DSS generator (or a generic DSS for a particular group of users, such as market researchers) will be developable by overcoming the primary technical impediments and it matters little what ultimate uses will be made of the DSS. It may be argued perhaps that the DSS designer doesn't need a clear understanding of ultimate uses of the system because the end-user will need to adapt the tool to their specific needs anyway. Or perhaps the argument can be made that the most critical impediments to widespread use of DSS at this early stage in their development are the technical impediments, the institutional impediments and depth of responsiveness to users needs will become more critical later.

Others, such as Beaumont, warn that meaningful research in an applications domain such as marketing must be driven by marketing problems and the needs of marketing management. If this is true, simply involving early on in the DSS design process one or two individuals from the applications group (i.e. marketing management) and using a prototyping process to test and improve the design may not be sufficient to adequately account for the needs of the intended users of the resulting system.

As co-director of NCGIA Initiative Four on the Use and Value of Geographic Information, I am attending this meeting primarily as an observer. I am interested in identifying those impediments in the realm of DSS which may be addressed most appropriately through a better understanding of the needs of potential users. The initiative four research team has been working towards development of tools for understanding the uses and value of geographic information. If a comprehensive understanding of user needs is important in addressing specific impediments to the development of DSS, some of' those tools may be useful to the research agenda arising out of I-6.

The primary objective of one of our efforts under 1-4 is to formally identify and verify the factors and processes influencing users to adopt a particular technology. From the identified factors and processes, the goal is to develop an analytically based diffusion model that can predict whether an innovation in its current state of development is likely to be widely adopted by a set of potential users. If the liklihood is non-adoption, the model should identify those technical, economic, institutional and social variables which are the most critical in impeding the adoption process. Although we are not currently studying the adoption of DSS, it is evident that diffusion modeling theory could be applied as one approach in gaining better insights on the uses and intended uses of DSS by marketing managment.

Some Talking Points on Spatial Decision Support Systems

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There are several issues in the area of SDSS which are worth exploring, and they run the gamut from hardware to software, model assumptions to programming styles, and data structures to operating systems. Among the topics we believe are suitable for discussion at the March meeting are the following.

Mixing intelligent Systems with Classical Modeling Approaches. Location-al location modeling traditionally has been based on a strict, logical set of rules. Optimization and heuristic algorithms have an obvious logic, and usually an obvious order of execution. Intelligent systems, an the other hand, rely on user interaction and the calculation of internal weighting factors. If a neural net model is used, hidden layers come into play. The difference between the classical modeling approaches and the intelligent system approach are great. In the former, the analyst (or at least the person who programed the algorithm) understands why each step is taken, each decision is made. in the latter, this is not the case. The internal weights are known only after an analysis is completed. This is a much different way of using computers, and one which lends itself to multiobjective problems with fuzzy structure.

Nonetheless, we believe there are ways for the two modeling approaches to work together. The classical approach could be used to generate a set of candidate solutions for the user consider. If the internal weights can be accessed at any given point, subroutines based on classic optimization techniques might provide suggested new solutions. This interaction between user supplied answers to questions such as "What don't you like about this solution?", the resulting weights they spawn, and classical current solution improvement strategies seems worth exploring.

Specialized Data Structures: There Use, Generation, and Display. Some analytic algorithms perform best when implemented with special data structures. Improvements in shortest path algorithms, for example, have come from special data structures rather than new solution techniques. Software developers are faced with a choice of using the existing slower data structures (most likely relational databases), generating data structures "on the fly" (that is changing the data structure each time a certain algorithm is invoked), or creating and maintaining a specialized data structure in addition to the relational model. Under what circumstances is one strategy to be preferred to the others? It would appear that the answer depends on the type of algorithm used and the number of times it is called. We have found, for example, that in analyses which are based in part on a traffic equilibrium solution the latter strategy appears worthwhile.

In addition to what Goodchild refers to as "real world" phenomena, SDSS also rely on "logical structures" some of which have a clear geographic component. Consider, for example, analyses which require explicit tracking and costing of intermodal transfers. If the transfer costs are asymmetric, logical intermodal transfer arcs at each possible node are needed for the calculation of such movements. These dummy nodes and arcs have, however, a distinct locational component. That is, they can be related via a pointer mechanism, to specific geographic locations. As a result,, there use can be reported in tabular form, or "logical maps" of their use can be popped up by clicking on a node. It would be of interest to explore how reporting the results form different types of location models might be improved by the use of logical mapping.

Taking Advantage of Improvements in Microcomputer Hardware. The development of GIA/SDSS system capabilities on personal computers has lagged behind that done on other development platforms. Some vendors, such as Calibre corporation, make use of DOS extenders. However, the Intel 386 and 486 chips have potential far in excess to mere extensions of DOS. These chips, which allow for memory mapping, can support several concurrent virtual machines. (It is estimated that 9 virtual machines is the practical upper bound to the 33 MHz 386 chip) . How can we take advantage of this power? Windows for multitasking are already a reality. We can, therefore, start a computationally complex subproblem, and continue with other tasks. Even more exciting is the use of dynamically linked windows. If SDSS software is developed to take advantage of dynamically linked windows, it would be possible, for example, to change transportation cost parameters or the shape of a tradeoff curve in one window and see the results mapped out in another.

Reviewing Existing Decision Support Systems. Many of the participants at this meeting have worked on DSS for various agencies. How close do these systems come to containing the four key modules of a SDSS described by Densham, and Goodchild? Based on the developers experience, are Denshan and Goodchild's modules exhaustive? Which aspects are easily implemented, which are difficult? Can the modules be fully integrated? Indeed, one question which needs to be discussed is whether analytic modeling capabilities should be fully integrated in a GIS package or whether they should only interface with existing packages. Some developers, including ourselves, have put simple analytic procedures, such as path finding, in the confines of a map based program while keeping the larger more complex models outside the map based system. The large models interact with the mapping programs only through the passage of files with pointers. We would be interested in discussing this issue with other developers and users. Indeed, a review of the lessons learned by the participants in developing SDSS software seems warranted.

Structured Query Language Interface. There are many database management packages available. What would be of enormous benefit is the development of an industry standard SQL. This would allow queries to be translated into the specific syntax of various database management packages. Intergraph, for example, has developed an SQL which translates spatial data queries so that one of three popular database management packages can be used in the background. As a result, the user need only learn one set of data query rules.

In terms of SDSS, are there specific preprocessing routines which should be incorporated into the SQL? Could a spatial interaction package be imbedded in the SQL so that a user could find all the locations with a specified log accessibility of a shopping opportunity? The elements which might make up an SDSS set of library routines which the SQL could call need to be evaluated.

Standard Libraries: Their Content and Structure. Related to the above point is the possibility of developing a library of callable functions for use by an SDSS. The contents of such a library and the ease of changing some of its structures and functions need to be studied. Such a library may benefit from the use of object oriented programming techniques. The OOPs property of inheritance would allow users to choose suitable parent structures and functions and then "mutate" the children in whatever way is suitable for the problem at hand. In such a system, late binding is probably preferred to early binding.

Monitoring, Updating, and Sensitivity Analyses in Spatial Decision Support Systems for Demand Forecasting

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Demand forecasting represents an important step of the planning process for many public and private sector activities. Public facilities such as parks and libraries are located and expanded to meet the needs of a population that is constantly changing in size and composition. Supermarkets and shopping malls also require forecasts of demand; such forecasts are instrumental in the estimation of future revenues and profits.

Demand forecasts are often produced using some form of spatial interaction model -- usually a singly-constrained Huff model, or a competing destinations model of the type developed and popularized by Fotheringham. These forecasts may be subsequently used in several ways. They may be used to evaluate the viability of new locations for additional facilities. They may be used to draw market boundaries. They may be used to forecast total revenue or patronage.

There are of course many uncertainties associated with these forecasts. Populations change in size and character; the attractiveness of the alternative destinations change, and the parameters indicating the importance of particular destination characteristics may themselves change over time.

These uncertainties make location and expansion decisions more difficult. In light of these uncertainties, the importance of monitoring, updating, and sensitivity analyses become apparent. Monitoring of changes in choice probabilities is important because it allows for the frequent updating of demand forecasts. Srivastava and Worsley (1986) have suggested how series of multinomial probabilities may be analyzed for "change points." Detection of such points in time series of spatial choices would allow estimation of current choice probabilities.

It is usual in the construction of spatial choice models to estimate the parameters of the model and construct confidence intervals around them to aid in understanding the significance of particular variables measuring destination attractiveness. More interesting and useful would be the construction of intervals around both parameters and destination variables that were consistent with the point estimates in the sense that they give rise to identical decisions.

For example, suppose a store manager faced the choice of either not expanding or expanding by a given size. Demand forecasts would be prepared to determine the likely revenues following such an expansion, and these would be compared with the costs of expansion. Suppose it is indicated that expansion is cost effective. For what range of the variables and the parameters is such expansion viable? Is it feasible that the variable or parameter values might fall outside of the "viability bound"? A similar procedure could be used to determine "switch points" for location decisions: at given parameter and variable values, the solution would switch from one location to another. In summary, improved decision making in spatial choice situations might be achieved by allowing the decision maker to explore 1) alternative parameter values, and 2) alternative destination attractiveness variables (e.g., through the use of incremental logit models), and by allowing the decision maker to monitor changes in choice probabilities.

Integrating Preference-Based, Location-Allocation and Behavioral Location Theory Methods in Decision-Support Systems for Locational Decisions

A Position Paper for the NCGIA SDSS Initiative
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Three different literatures exist to provide decision support in locational decision-making. Each focuses on a set of needs of people who make location decisions and each is thought to be most appropriate for a particular decision context. All three pre-date the development of computer-based geographical information and analysis systems and GIS/GIA have developed without reference to them. Spatial Decision Support System users will want to use these methods in the future. The problems of integrating the three methods in operational GIS/GIA systems need to be identified and solved.

The three methods are: 1. Preference based decision analysis: designed to aid decisionmakers express and clarify their preferences and to judge alternatives that differ in values on key attributes. 2. Location-allocation models: designed to aid decision-makers by finding combinations of locations that are optimal with respect to pre-defined objectives. 3. Location theory: designed to describe how decision makers determine locations, activities, and prices (normative theory), or how, in fact, they select locations, activities and prices (behavioral theory).

Preference based decision analysis assumes that the only relevant knowledge needed to assist locational decision-making is the goals, values and preferences of the decision-maker. In this approach an analyst elicits the preferences of decision-makers, reconciles differences among individuals that may exist, and then selects, from a pre-identified set of alternatives, the location which best satisfies preferences subject to given constraints. This literature is strong in the systematic treatment of the human selection process from pre-defined alternatives (von Winterfeldt and Edwards, 1986; Keeney, 1980).

In location-allocation modeling, multiple locations are found that are optimal with respect to a well-defined single or multiple objective function by systematically searching through the usually very large number of possible alternatives. Where the criteria and objectives can be translated into clearly defined (structured) objective functions, this approach can find optimal locations by established multi-objective programming methods. This literature is strong in the systematic way in which it determines the locations that are optimal for the specified objectives (Love, et al., 1988; Ghosh and Rushton, 1987).

In models based on location theory, conjectural assumptions are made about the behavior of actors. These assumptions have different degrees of empirical realism. Locations and activities are then identified that are consistent with the particular assumptions of the model. Sometimes, spatial equilibrium conditions are specified and some models determine, analytically or by simulation, the spatial and activity characteristics of the resulting equilibrium condition. Since alternative location decisions will have different consequences, it is necessary to determine these consequences in order to judge the merits of alternative location decisions. This literature is strong in replicating aspects of reality that may change as a consequence of particular location decisions.

Research is needed to develop and test in prototype systems these three functions. For the first, preference elicitation, a number of commercial systems already exist. These could be incorporated in GIS/GIA systems.

For the second, location-allocation models, we have developed a prototype SDSS system at The University of Iowa and have tested it with a government task force that was required by law to submit a plan for the geographical restructuring of Iowa's Area Education Agencies. The interactive system allows a panel of decision makers to input their criteria and constraints and the system finds the administrative centers and their boundaries that optimize their criteria. The system produces maps and performance statistics for the regionalization plans. By examining these, they are able to modify their criteria and possibly reach a concensus on the solution to their problem. The system also allows users to control the eligibility of places to enter the solution and the permanence of boundaries. The plan produced by the Task Force using the system was adopted by the Iowa Department of Education and subsequently submitted to the Iowa Legislature, (Rushton, et al., 1989). The system can be used for a variety of location and regionalization problems, including political redistricting.

In the prototype test, two 386 chip based PC computers were connected by cable. One computer displayed the results of an analysis while, frequently, the other analysed a revised set of objectives and constraints requested by decision-makers. The system was designed and programmed by Paul Densham in 1987-88 and expanded and tested by a project group in 1989. The system is able to solve all location-allocation problems and objective functions that are compatible with Hillsman's (1984) unified linear model. In addition, the system has a heuristic spatial assignment module which can be used to iteratively equalize spatial assignments between regions to meet threshold constraints with least decrease in geographical accessibility in the system. The system also has a facility for controlling changes in boundaries of regions and permissable or forced spatial interactions as stipulated by users. It also includes the data input elements and shortest path algorithms of Goodchild and Noronha (1983) and produces many of their output tables. The methods of data organization and computational methods, however, have been radically revised and large location-allocation problems can be solved by heuristic methods on personal computers in times that are short enough to become a part of a normal decision-making process. For example, within ten minutes time, in the prototype test of the Area Education Problem, a problem consisting of 403 demand nodes and 57 candidate nodes could be solved as a twelve median problem with maximum distance constraints. After ten minutes, decision-makers could examine a map of the locations of the centers, the allocations of school districts, and regional boundaries. Zoom capability in the system allowed them to examine local areas in more detail. Details are provided in Densham, 1990, Densham and Rushton, 1990; and Armstrong, et al., 1990.

Research is needed to determine how models based on normative and behavioral location theory can be integrated into SDSS. This research should distinguish two purposes with different requirements. First, is the need of users to anticipate likely reactions of other actors to their decisions. Retail marketing is one such area where SDSS are clearly of limited usefullness if they do not have a modeling capability to compute expected future equilibrium conditions. The second purpose is the need of researchers to construct new theory and models. A flexibly organized SDSS could serve as an instrument for constructing new theory if used to conduct experiments in controlled situations or if used to study empirically historic changes in economic activities.

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NCGIA Initiative 6
Position Paper
Prime Wild GIS Inc.

Introduction

Over the past eighteen months we have prototyped, developed specifications and implemented additional facilities to provide some SDSS like capabilities in our system. The initiative for this effort stemmed from a need to allow users to develop and customise analysis procedures.

We developed a technique in which a solution procedure may be specified as a tree. Nodes in the tree represent analytic operations and links between nodes, termed data flows, represent how information should flow from node to node. By executing the analytic operations represented by nodes in tree order, data can flow through the tree culminating in one or more data flows which represent the result of a complex series of analysis operations. The specification is recursive and allows complex operations to be encapsulated at increasing levels of abstraction. There are strong parallels between this approach and relational database navigation and query optimisation procedures.

The data flow model and a simple graphic server for user interaction were developed as prototypes and the concepts tested out with a small location allocation problem in conjunction with Paul Densham. After evaluating the prototype:

- data flows were generalised to full relations which may contain spatial data base object identifiers and attributes;
- an additional "geometry" data type for data flows was implemented in a similar vein to Dave Abel's work on SIRO DBMS;
- database manipulation and report generation capabilities were brought up to the command language level; and
- additional branch and loop facilities were specified to control execution of solution procedures.

Another result of the prototype evaluation was to formally adopt Sprague's model of a DSS which specifies the different users and levels of technology which underpin a DSS.

Architecture

Four software components; a command language, data flow management facilities, processing functions and a graphics subsystem form the core of the development and are used in almost all circumstances. Depending on a users characteristics, three additional components may be more or less relevant, these being a processing function development library, an application builder and a user interface management system. Figure 1 outlines interactions between users, the various software components and data stores in the system.

The command language accepts input from a user at a keyboard, from a command procedure which contains a series of commands and control flow constructs, or from an input stream generated by a user application. Once a command is entered, the system determines whether the command may be processed internally, or whether it should be passed on to a processing function or the graphics subsystem. Invalid commands are simply reported to the user. Data flow management commands are processed internally and may be used to create, read, write and query data flows. Other internal commands allow variable manipulation, ahas specification, flow control, looping and command line editing. The command language is interpretive and lends itself to the iterative development of solution procedures.

Data flows are relational tables, whose structure is defined by user commands, processing functions or the graphics subsystem. The contents of data flows are generated by processing functions or the graphics subsystem and may consist of database object identifiers and additional attribute values generated by processing functions. Data flows and their definitions are stored in a clipboard which is a user specific database. Commands are provided to manipulate clipboards.

A processing function is a discrete analysis operation. Processing functions are the building blocks which actually "do the work" in a particular solution procedure. Processing functions are initiated by commands and act as servers to the solution procedure. The general model of a processing function consists of a number of parts:

- zero or more input data flows which represent the information to be processed;
- zero or more parameters which are specific to the processing function;
- the actual processing function to perform the work; and

- zero or more output data flows which represent the result of the analysis operation.

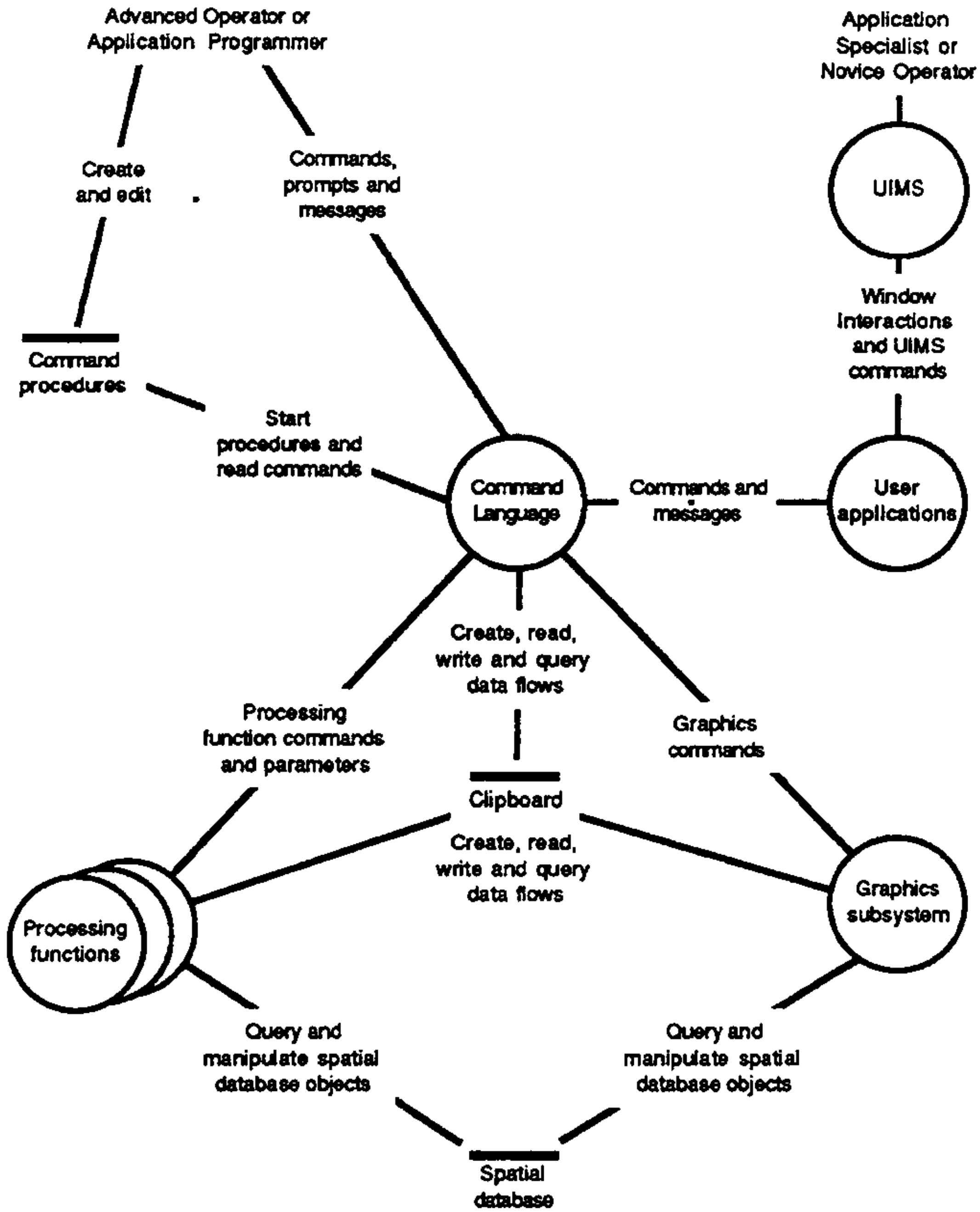

Figure 1. Software component interactions

Since all processing functions follow this model, it is possible to combine them into networks which specify the operations to perform and the order of processing. Additional processing functions may be developed using a processing function development library. This library is designed to allow programmers to focus on the algorithmic aspects of problems and not the mundane issues associated with making functions servers, interpreting command lines and so forth. This extends to the provision of a number of different processing function classes which may be modified and extended in specific cases. For example, one class simply retrieves each input entity in turn and produces it for the underlying algorithm, another class performs a simple "spatial join" on input data flows and produces the joined information a row at a time for the algorithm. Although processing functions must be developed with normal software development techniques, it is not necessary to "compile" them into the command language.

The graphics subsystem allows user interaction with a representation of the information being analysed. Objects and their attributes may be displayed in various formats as required. Users may identify objects on the display in order to generate new data flows which may be used in subsequent analysis operations. Local capabilities are provided to allow pan, zoom, visibility control and simple data capture. Requests to display data contained in data flows and to pick displayed information may be issued with the command language.

An application builder, which we are still thinking about, will provide a visual programming environment to allow users to develop and customise applications by manipulating icons which represent processing functions, data flows, command inputs and control structures. The specific requirements for this facility are not determined and form an an area of on-going study. We may find that such a sophisticated approach is not needed and one based more on the "application class" technique demonstrated with Next and Objective C is more appropriate.

The user interface management system will provide facilities including icons, dynamic menus, sliders, pop-up windows and buttons to develop specific user applications using standard programming techniques. There is continuing debate amongst ourselves about the "besf standard to hang our hat upon, and OpenLook appears to the the star in the ascendancy at present. Currently specific user applications which require sophisticated window based front ends are implemented with SUNTOOLS, a set of user interface primitives provided by SUN.

Future Work

Our immediate interests lie in the following areas:

- integration of SDSS in a heterogeneous network of computers with multiple data sources;
- development of a solution to the attribute aggregation and disaggregation problem;
- development of automated spatial filtering procedures and integration with attribute aggregation and disaggregation facilities;
- integration of a statistical package with the system and enhancement of the user interface and graphical subsystem capabilities to complement the package;
- following any work done on development of data models for SDSS, in particular, we are interested in models applicable to environmental modeling, location analysis, and those which express temporal information; and
- participating in the development of a standardised topologic data model for spatial information.

In the longer term we are interested in two areas, development of generic prototypes aimed at general application areas and integration of expert system capabilities with an emphasis on aiding solution procedure specification and development.

More on the Research Agenda for SDSS

by

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Introduction

This was going to be entitled "SDSS: A Research Agenda" but then I found that Densham and Goodchild (1989) stole my title last year at the Orlando GIS Meeting where they presented a paper on just that topic (not only that but half the position papers seem to have done the same thing). If the research agenda has already been settled can we present any reactions to their observations? Have things changed much? Are there some aspects of the research agenda which might be expanded upon in the light of my own research and that of my colleagues in Computer Science at the University of Calgary? The present position paper attempts a brief elaboration of answers to these questions.

The User Interface

Densham and Goodchild (1989, p. 713) address this topic directly and, of course, it forms the thrust of Gould's (1989) paper in the same volume. This is obviously a most important item and it is one in which many other disciplines are working. Few if any geographers appear to be making use of this research including, for example, the work of Rasmussen (1986,1988). Rasmussen's monograph on Information Processing and Human-Machine Interaction could well serve as a primer on many of the issues involved in the design of an SDSS. Rasmussen also addresses such topics as emergency management which might play an important role in any municipal GIS or SDSS. If we are not to continue to reinvent the wheel each time it might be a good idea to look at this work in cognate disciples from which we can learn so much. A quick perusal of the work of Rasmussen and others will bring SDSS researchers up to speed on this topic.

Alternative Structures and Alternative Platforms

Object oriented databases. These appear to be the way of the future as evidenced in the work of Rushton, Lolonis and Densharn and their collaborators. Recent discussions with Tom Poiker at the Ottawa GIS meeting showed that he was excited about programming a GIS on the NeXT computer using an object oriented database and the C programming environment found on that system. Since color is likely to come to this system in the near future it might well represent a powerful and affordable environment for SDSS development.

Neural Networks. Lots of ready to apply software out there, a few pioneering papers suggesting applications in geography (cf. M. Phipps' paper in **Geographical Analysis** last year, 1989) but neural networks have yet to be tied into SDSS research. This would appear to be a major opportunity which is being neglected.

Blackboard Architectures. An introduction to these systems is provided by Nii (1989). Nii discusses their potential for application in the field of planning and cites the work of Hayes-Roth et al. 1979 and their research on the simulation of the human planning process. Nobody in SDSS research seems to be discussing them. Why not? Densham and Goodchild (1989) suggest different types of knowledge (environmental, procedural and structural) need to be incorporated into the SDSS and this might well be handled most effectively within the blackboard model and architecture.

Massive Data Compression

SDSS may need access to vast amounts of data in order to be effective. If these systems are also to be efficient and interactive and not require elaborate platforms which are beyond the budgets of all but the largest of departments then data compression will be of vital importance in the dissemination of this type of software. Perhaps this is one reason why SDSS have been talked about for almost two decades but have gone nowhere in practical terms. We already have such tricks as run-length encoding and quadtrees among others but what we want is something much better perhaps by an order of magnitude. And this is what Barnsley and Sloan and fractals appear to be offering (see the March, 1990 issue of Scientific American, pp. 77-78). Although there is some scepticism reported in the article, a data compression technique which is at least an order of magnitude better than existing procedures could be one of the most important developments to occur in GIS and SDSS.

My Own Research - Attempting to Resolve the Bottleneck of Knowledge Acquisition

Densham and Goodchild (1989, p. 714) note that: "a SDSS should incorporate knowledge used by expert analysts to guide the formulation of the problem, the articulation of the desired characteristics of the solution, and the design and execution of a solution process ... The elicitation and incorporation of this knowledge is a major avenue for research." At the University of Calgary a number of researchers in the Knowledge Science Institute (which is housed by the Computer Science Department) are involved in knowledge elicitation and engineering. Their research has led to a several Knowledge Acquisition for Knowledge-Based Systems Workshops (or KAWs). The first being held in Banff in 1986. Much of this research has subsequently been published in the International Journal of Man-Machine Studies and in two volumes edited by Gaines and Boose (1988) and by Boose and Gaines (1988), respectively. In the second of these volumes Shaw and Gaines (1988) describe software which they have developed for knowledge elicitation and rule generation for the codifying of the expert knowledge. This is an interactive package for the Macintosh which has been used in several geographical studies and could provide the expert knowledge which Densham and Goodchild are suggesting should be incorporated into the SDSS. It is interesting to note that much of the methodology which Shaw and Gaines deploy has been widely used at one time or another within the discipline of geography. Their procedures include the use of personal construct theory and the repertory grid, and such data reduction techniques as principal component analysis and cluster analysis prior to the generation of rules for the expert system shell. In the Department of Geography at the University of Calgary we have used later incarnations of KSSO to elicit knowledge from computer mapping experts, from geologists and from fire department personnel. The latter study was exploratory work in trying to develop an SDSS for the location of fire stations and the deployment of fire department equipment. Software such as KSSO is designed to overcome a problem which was described by Mark Twain over 100 years ago when he was a cub pilot on the Mississippi and trying to extract expert knowledge on the art of piloting from a seasoned master. Twain asks his mentor how he is ever going to be able to tell the difference between a wind reef and a bluff reef. The surly reply comes back:

> "I can't tell you it is an instinct. By and by you will just naturally know one from the other, but you will never be able to explain why or how you know them apart." (Twain, 1980, p.66)

Deconstructing SDSS: Use and Abuse

Harley has recently published a lengthy article on Deconstructing the Map in Cartographica and there are reportedly to be a number of critical responses in the next issue of Cartographica. I have suggested similar approaches might be used with GIS and the argument might well be (and perhaps with more validity) extended to SDSS. The are many issues of concern relating to what goes into an SDSS. What are the decision criteria to be? Whose value judgments, weightings, goals, and objectives are to be used? These are all issues which should part of the research agenda.

The misuse and abuse of SDSS is another topic worth addressing in the research agenda. Some comments in this vein with respect to GIS have already been broached (cf Waters, 1989, and the references contained therein).

Education

It seems to have been neglected in recent work on SDSS, although certainly not in earlier related research on location-allocation models. Since this is part of the NCGIA mandate we should give serious consideration to the development of an IDRISI-like package for SDSS which might well interface with a low-cost GIS.

Conclusion

Finally, in preparation for the meeting we might benefit by taking the advice of Penzias (1989) who suggests that bad ideas might eventually prove to be just as useful as good ones in stimulating new developments. Penzias also suggests that simply asking questions is another effective way of advancing the research frontier. He recommends questions that illuminate, not those that destroy and notes: "Sometimes we don't know what we don't know until someone asks the question."

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Position Paper on Spatial Decision Support Systems

Prepared for the National Center for Geographic Information
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Importance of this research to the planning profession.

Although I appreciate the need to narrow the applications to be considered, and feel that the topics of marketing, retailing, location theory and socioeconomic models provide a good set of applications, I hope that the needs of other professionals are considered in parallel during the research process. I am particularly concerned that the advancement of analysis capabilities in GIS be useful to urban and regional planners. It is true that the retailing community has been relatively slow in adopting the new GIS technology and may be expected to benefit greatly from that technology in the next few years. On the other hand, I perceive that there may be some misconception in the assumption that the planning profession is very far along the GIS learning curve. It is also clear that many of the components of a Spatial Decision Support System (SDSS), with enhanced modeling capabilities, improved user interfaces, and included expert knowledge, will benefit both retailers and planners. However, both specific needs and available resources are likely to differ between, these two fields. The call for improvements along each of these dimensions has also been coming from planning academics for the past several years (Harris, 1989; Kim. et. al, 1989)

In recent survey analysis, we have concluded that most planners in local agencies currently have extremely limited access to GIS technology. Although their computing capabilities have been increasing exponentially, the predominant platform in 1989 was a stand-alone microcomputer. The planners reported that their most severe problems with their current computing capabilities were lack of training, funding difficulties, and the lack of planning-related software. There is no corresponding lack of interest in the technology, however, with over half of the planning agencies (even from quite small jurisdictions) expressing their intention to adopt the technology in the near future (French and Wiggins, 1989a; French, Heffernon and Wiggins, 1989b).

In giving a series of short courses on GIS to practicing planners we have also become increasingly aware of the inflated expectations of many of these potential users about the current analysis capabilities of these systems, their inability to ask vendors hard questions about these capabilities, and, perhaps most troubling, their underestimation of the importance, expense, and time required in the development of adequate digital databases (both graphic and attribute). We fear, for urban planning, the possibility of another failure along the lines of the demise of the largescale urban models of the 1960s (Lee, 1973), and we hope that this may be avoided through timely research and education efforts. The funding sources for these research and education efforts remains unclear to planning academics who are: interested in computer applications in planning. Only the largest academic planning departments currently have the capability to conduct such research and education efforts, and funding has been minimal.

Changes in modeling capability due to increased availability of parcel-level GIS.

The underestimation of GIS costs by planning agencies is likely to be particularly true for those local agencies adopting parcel-level GIS. And yet much of the power of the new GIS technology for urban analysis and modeling will come from the increasing capability to have current parcel-level data. We feel that a crucial research area is the impacts on and potential improvements in the existing land use-transportation models of the increased availability of parcel level data. We have Ph.D. dissertation research work underway on this topic.

On the other hand, many of the needs of local planning agencies (as opposed to public works departments and assessors offices) may be better handled at the block or small-area level of analysis. This is particularly true since many of these agencies will have access only to microcomputer technology. The ability to determine the appropriate level of geographic disaggregation for a specific analysis, and to aggregate correctly (e.g., correct handling of one-to-many, many-to-one, and many-to-many relationships) needs careful thought. Aggregation procedures for the attribute data in GIS systems has received too little attention. For example, in aggregating up to a block level from a parcel-level database from a typical assessor's file, we encounter multiple-owners on a single parcel (condos), multiple residences on a single parcel (apartments), and multiple land uses on a sing e block. Some of these issues are partially solved by SQL--based databases, but some conceptual issues are not. For example, one of the most-cited use of GIS by planners is overlay analysis for site selection and suitability analysis. Correct union and intersection procedures for coverages of mixed data types (i.e., the nominal and interval data found on soil maps vs. population density maps), are difficult to implement in most current GIS packages. We feel that this area is particularly important for the improvement of existing GIS packages and an appropriate area for the incorporation of expert systems technology into GIS.

Lessons from MIT's Project Athena.

Several lessons from MIT's Project Athena may prove useful to this research effort. In early years ,Athena philosophy was to recreate applications packages from scratch on campus for the new workstation technology (e.g., recreate a Lotus-like spreadsheet program locally, etc.). I think it is fairly clear now that university research efforts in software development must be carefully considered, and that academic redevelopment of private-sector vendors products is not terribly productive. Work on program linkages, front-ends, interface innovations, standard development, etc. seems to be more in line with what the university may do best. Providing feedback to the vendors about their products and offering suggestions for future development also seems to be a valuable academic role. As academics, we need to make sure that taking such a role with the private sector is also valued by our colleagues.

It seems clear that the software market of 1990 will see increasing use of modularity, with users customizing packages to their own uses. For example, it is pretty clear that every GIS package cannot continue to develop their own CAD tools to the extent necessary to compete with the best CAD programs, etc. It is also appears clear that transportation-related packages will have better location-allocation algorithms then GIS packages oriented toward regional planning. No one package will even come close to doing everything in the modeling area well, and this probably shouldn't even be anyone's goal. However, developing a Spatial Decision Support System that combines the best points of many packages with good linkages and interfaces, seems both a good research area and also a good place for the use of expert systems technology.

Working daily in a highly-networked, distributed environment with multi-tasking workstations spoils one to the point where a standalone microcomputer appears pretty minimal. With large data requirements and multiple users, it is clear that GIS technology will move more and more to a distributed environment with multiple platforms. Research topics that are important include issues of data security, integrity in updating both graphics and attribute data, and translation capabilities when multiple packages are required (Ferreira and Menendez, 1988; Ferreira, 1990).

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SPATIAL DECISION SUPPORT SYSTEMS:

A Position Paper on the

Research Agenda for NCGIA Initiative 6

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Introduction

The author wishes to first express his sincerest appreciation for this opportunity to contribute his views an this topic.

Background

The views contained within this paper have been strongly influenced by a specific- undertaking, the author's doctoral dissertation on the topic of autodistricting census data collection units.

The actual autodistricting capacity that has been developed and implemented as part of the 1991 Census production process is most simply described as a set of models/algorithms imbedded within a standard Geographical Information System (ARC/info). The manner in which this autodistricting capacity has been linked to the traditional, manually-oriented, districting process imbues it with many of the characteristics of a Spatial Decision Support System (SDSS).

Current Plans for initiative 6

The proposed topics and related scopes appear to be appropriate if the breadth of the subject area is to be- adequately addressed. T-n light of the timeline for the initiative, it should be expected, however, that the depth of individual treatments will have to be variable due to the variable degree of difficulty they pose and the availability of existing research materials.

Other Important Topics

Based on research experiences with an autodistricting SDSS, I wish to recommend that two topic areas be pursued with priority (in spite of the tight timeframes and existing workload) because of the role they play in using a SDSS easily and with confidence.

1. Testing Strategies and Method Selection Mechanisms

The Complete and comprehensive testing of SDSSs tends to be costprohibitive given the number of possible/probable combinations of solution subprocesses for a given problem. This difficulty increases for SDSSs capable of being applied to a family of similar problems. For example, census autodistricting can be applied to the creation of individual (contiguous) enumeration areas, (discontiguous) enumeration workloads, or (contiguous) commissioner/supervisor districts with relatively few changes in parameters.

Such testing is complicated further if "tool"/method selection is automated. An adequately large and representative sample of test runs is needed to validate the selection mechanism or mechanisms in addition to the testing of the individual methods.

Indeed, the control of method selection may be a topic worthy of consideration unto itself since, as the size and power of SDSSs increases, the need to reduce the number of proposed solutions to a manageable level also increases.

An important element of the method selection procedure is the availability and suitability of spatial indicies to assist in case differentiation.

2. Communicating with SDSSs

The current terms of reference for Initiative 6 make reference to the importance of graphics as a mechanism for displaying results and for providing an interactive user interface.

It is useful to make explicit the contribution and value of interactive graphics as a mechanism for specifying model parameters or projection formulae (as has been implemented for the SURF and TURF systems at Statistics Canada).

There is obviously a direct link between this Initiative and a significant number of the other Initiatives. one worth emphasizing, in my view, is the linkage with Initiative 2, Languages of Spatial Relationships.

Designers of SDSSs often require a convenient mechanism for specifying models or model enhancements in a precise and specific manner. A language for specifying spatial operators and -relationships is, therefore, an essential component of the user interface for an effective SDSS.

(Note: a large number of such operators were enumerated -- but not published -- during the early stages of my dissertation research. These specifications can be made available to researchers working in this area.)

Conclusions

With such a broad waterfront of topics, it is difficult to select and assign priority to the most important elements. This short paper has suggested that the testing and use of SDSSs should be given as Much attention as their design and development if they are going to be positively received by the sponsors/users.

SDSS in Public-sector Engineering

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The Lion and the Mouse: A parable

In a land not so far away, a mouse worked diligently at his patio desk amid a clutter of papers, notebooks and strange looking instruments. As he paused to wipe his spectacles with a kerchief taken from the pocket of his rumpled red vest, along came a lion.

"Good day friend mouse," said the lion. "What occupies your time so intensely on this lovely Spring day?"

"I am a finder of cheese, kind lion," replied the mouse replacing his spectacles and leaning back in his chair with his tiny hands folded across his chest. "The gate behind me leads to a maze, and somewhere within that maze is a treasure of cheese. I have been retained to help find the cheese, to determine if it is suitable for consumption, and worth the effort to retrieve."

"And what of this clutter?" asked the lion.

"These are my tools," the mouse made a prideful sweeping gesture with his arms. "They are very good and powerfid tools, and I have learned to use them well. I collect my data, take my measurements, do many calculations, write my reports, and present my recommendations. My reputation is very good and my advice is sought by many.

The lion slowly shook his, head. "Dear mouse, your tools are old and your methods are slow. I know of better things and will gladly show you the way." With that the lion removed from a gleaming crystal chest, a sparkling vial containing an emerald potion. "Drink of this elixir," spoke the lion in a breathless tone "an you will have insight and vision beyond your imagination.

"What's in it?" inquired the mouse sniffing the container cautiously.

"That is not important," said the lion with a terse wave of his hand. Join me in a sip, and you will reap magnificent rewards.

With a slight hesitation, the mouse took a sip from the container. Immediately, he felt warm and good, and had the sensation of being lighter than air; of floating on a cloud. Suddenly, his feet left the ground and he rose higher and higher, soon rising above the walls of the maze. He could see not one treasure of cheese, but many. And he could see clearly the paths to each. 'This is wonderful," cried the mouse rising still higher. Soon he could see other mazes; some clearly, some obscured by clouds, some containing cheese treasures, some, alas, with none.

"Look there!" whispered the lion, pointing to a thicket near one of the mazes where an evil pussy cat lay crouched, eyes fixed on the entrance to the maze. "And there!" to a wicked mouse trap laying poised for an unsuspecting victim.

"Never before have I seen such things," said the mouse in wonderment. "With this potion, I can do things that I never dreamed. You must tell me what this is; what is in your magic, elixir."

"I will give you all you want, " said the lion with pride. "I am eager to help you and others so that we all might prosper, and so that we will live in a better place.

As suddenly as it began, the sensation of the potion left. The mouse thanked the lion for this wonderful gift, and with the warmth of a renewed friendship, the two parted company.

The following Spring, the lion once again found himself near the workplace of the mouse. As he approached, he saw his friend sitting at his aging desk among new piles of paper and familiar looking instruments. Incredulously, the lion addressed the mouse. "Why are you not working, my friend. The day is new and there is much need for your services."

"But I am working, dear lion, and business is better than ever!" the mouse said with a satisfied look on his tiny face. "How good it is to see you again!"

"But my potion! Have you not changed your ways?" cried the lion. "Is not my potion the solution to all your problems?"

The mouse carefully laid down his pencil and leaned back thoughtfully in his chair. "My friend, your potion is very good, and I use it more and more in my work. I keep it in a special place among the most valuable tools of my trade." The mouse unlocked and opened the door to a small cabinet and pointed to the half-full vial containing the emerald potion. "Your wonderful potion allows me to do things I could not do before; to do some things much more quickly than before, to do some things more accurately than before. But there are things I must do for which your potion is of little use, such as testing the quality of my cheese, or comparing the costs of retrieving different cheese treasures."

"I see," said the lion placing a large paw over his mouth and stroking his chin. "Hmmm... a cheese tasting potion... what an intriguing idea!"

"As a matter of fact," said the mouse with a smile, "I've been thinking about that very thing myself." The mouse carefully reached into his cabinet of tools and removed a tiny flask containing a sparkling blue liquid. "Perhaps, friend lion, you'd care to join me in a sip?"

SDDS in Civil Engineering

From my perspective, the engineering community has been slow to embrace the technology of spatial decision support systems (SDSS), though the potential from doing so would seem to be enormous. This is not to say that GIS is not being at least studied by engineering planners (indeed, some of the most ambitious GIS efforts ongoing today are automated mapping and facilities management (AM/FM) applications motivated by infrastructure management and rehabilitation concerns). But in each instance, the technology is being employed not for doing engineering analysis, but for handling data.

There are at least four major reasons that engineering applications are following, rather than leading developments within the SDSS technology:

1. Civil engineering has traditionally been slow to adopt new technologies. This is not only true for computer hardware and software technologies, but for advances in analytical methods and modeling paradigms as well. Factors contributing to this include the low volume/high profit margin associated with civil works, and increasingly clouded liability issues.

2. The compute environment of GIS tends to follow that of business computing (large data inputs feeding relatively simple algorithms) rather then engineering computing (sparse data inputs feeding complex algorithms), see Figure 1. Meaningful spatial decision support systems in the engineering community are possible only with dramatic increases in modeling environments that are tightly coupled with GIS-type data representations.

3. The management of engineering typically involves fairly rigid investment formulae (for such things as capital equipment, training, and facilities). This decision-making environment does not favor the acquisition of state-of-the-art technology on a regular, recurring basis. From another perspective, the determination of benefits resulting from the use of modem SDSS is less well understood (and accepted) in the engineering community than is the determination of costs.

4. Engineering applications that could benefit most from sophisticated SDSS tend to be Ad Hoc, precluding the justification for large-scale database development and verification

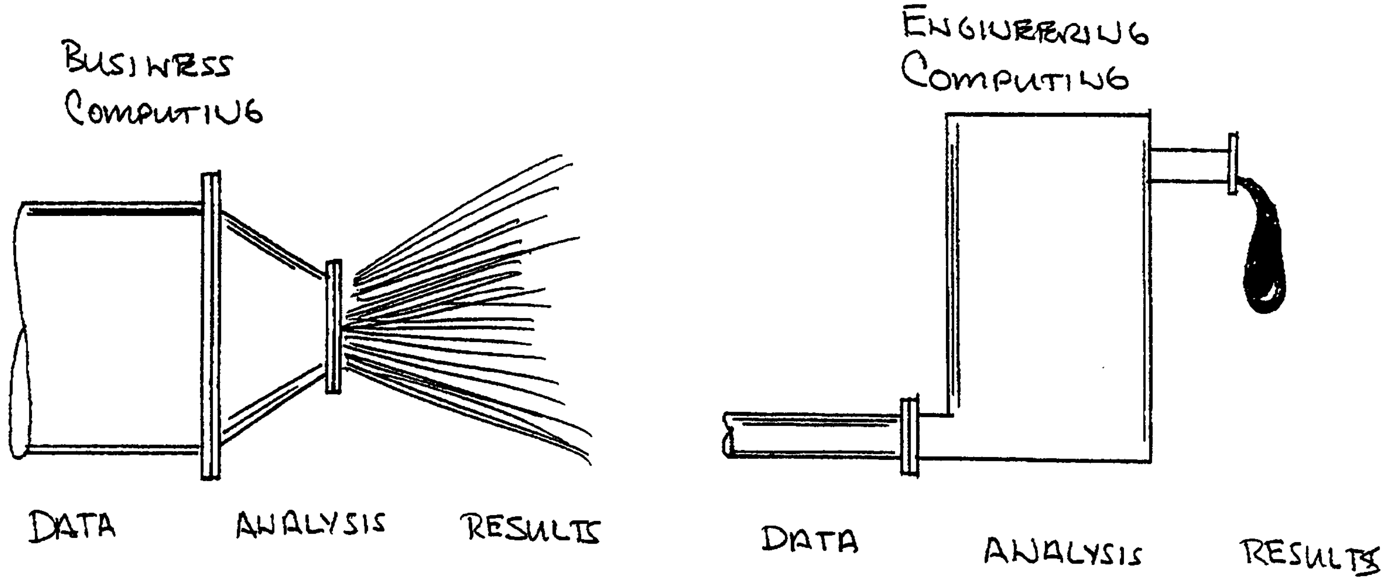

Figure 1. The business compute environment is characterized by large data inputs but relatively simple algorithms whereas engineering computing requires fairly little data, but extremely complex algorithms. The GIS compute environment more closely mirrors that of the business domain.

Because a number of more far-sighted third-party Architecture and Engineering (A&E) firms are launching major marketing efforts aimed at the engineering community, and are beginning to see return on these investments, it may be concluded that engineers are starting to come around. However, I should like to point out that these firms are, for the most part, no longer selling engineering services but rather data management services. Meaningful integration of spatial data structures with engineering analytical techniques is not seen outside the university environment.

The issue becomes one of acceptance: "At what point does a technology become an accepted method for doing business within the engineering community?" Based on past experience, it would seem that we have a long way to go before modem SDSS is an accepted technology for conducting engineering analysis. Figure 2 presents a generalized profile of the tools that are presently available to engineers involved with spatial planning, management, and design showing the relative degree of acceptance of each within the engineering community. Note that while GIS has become relatively well. accepted by engineers who appreciate the importance of a spatial dimension to data management, SDSS lags behind.

Lastly, for SDSS to become an integral part of engineering analysis, there will have to be a broadening of perspective. Figure 3 shows the present potential for SDSS to be used in engineering analysis according to four functional areas; management, operations, planning and design, and research. SDSS technology is presently most able to address management issues requiring information synthesis and display. Systems for operations, planning and design have not been developed (at even the prototype level), and research systems have not even been conceptualized.

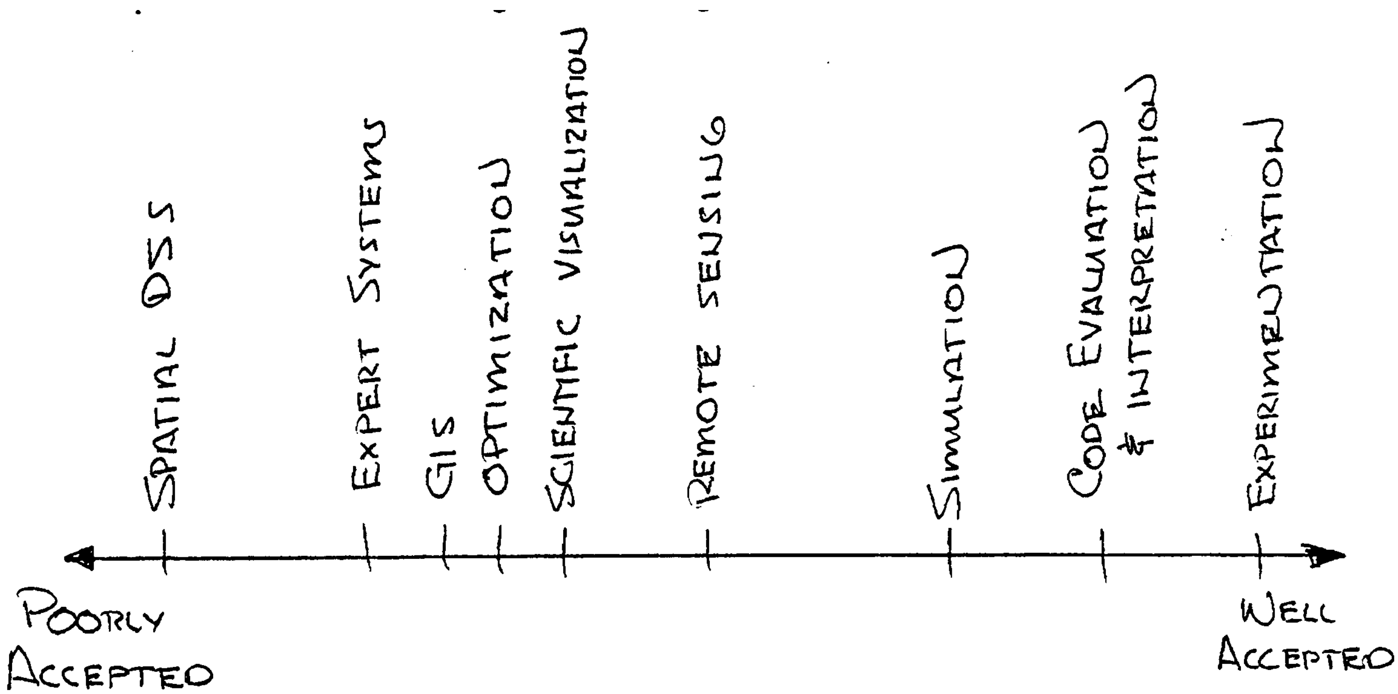

Figure 2. Tools presently available to engineers for spatial analysis showing relative degree of acceptance. Movement to the right is very slow.

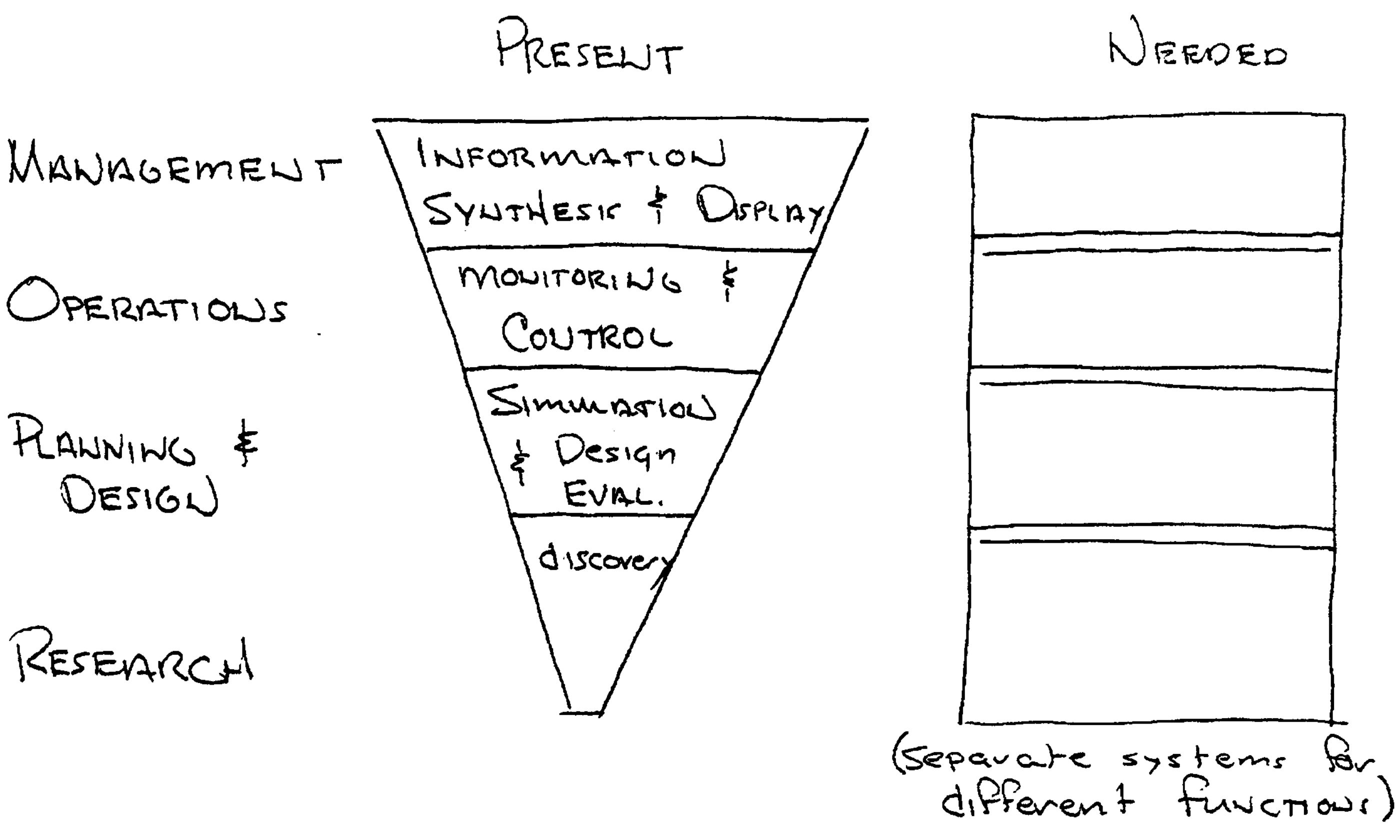

Figure 3. Present GIS technology is most appropriate for engineering management functions such as simple information synthesis and display; presenting results, etc. To be more central to a wider array of engineering problem solving environments, new functional forms of SDSS for must be developed for engineering operations, design and research.

A Focus on Spatial Decision Support Systems

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The goal of this meeting is to refine the research agenda for Initiative 6, Spatial Decision Support Systems (SDSS), and to identify research issues that should be addressed by the Center. Given the topic, SDSS, our first reaction may be to focus on the class of problems that can be solved. However, if we step back and look at the evolution of DSS (Decision Support System) in general, we find two other dimensions that require addressing. They are the underlying availability of data and usability.

As technology evolved from the DP environment for processing highly structured operational processes, through the MIS, into the domain of the less structured, less process-oriented environment of DSS, there is an emerging dependency on two key ingredients. One is the DBMS (database management system). The DBMS provides the technology to store and access data independent of applications thus making data accessible. The other is the integration of decision maker and 'system' to solve problems.

The evolution of geographic processing, I believe, is following a similar trend. It started with mapping, then operational and inventorying processing, then analysis, and now the future SDSS. However, the underlying expectations of the availability of spatial data is not as easily achieved. Consider a simple relational data model for a DSS. One conceptual model of the data is tables with relationships between tables formed by a common index. In this environment data can be 'rearranged' to fit the decision makers mental model. Thus it becomes 'easy' to identify and understand relationships among the different variables. There is no equivalent conceptual model for spatial data. What is needed is the development of a conceptual model(s) that can describe relationships between entities, topological properties, and scale context along with a temporal element. Future research should also identify which data structures, if any, efficiently support a large class of problems. Identifying the underlying data model for SDSS will help answer the question if a GIS system is rich enough to support SDSS, or are transformations required from GIS to a SDSS? Thus:

- For each class of problems addressed, it is necessary that we identify the supporting data model.
  - What is needed
  - In what form

The second area of concern is usability. Under usability I would include user interface, language, functions, adaptability and reporting. The decision making process starts with the identification of a problem, then the generation of a set of alternatives, followed by evaluation and selection of the best alternative. For this process to work efficiently the SDSS model must be adaptive to the decision maker. Ideally, the SDSS should possess a "learning" capability that will continually refine the model based on use. This implies the underlying model is dynamic via use over time. As part of the research initiative on SDSS a focus should be placed on identifying the usability issues and constraints associated with each class of problems addressed. My concern here is how a SDSS will support the model of the decision maker at different levels within an enterprise. This may be an overlap with Initiative Four (Use and Value of Geographic Information) and its efforts to define a taxonomy on Geographic Information uses. Thus we should:

- Identify usability within the enterprise
  - Who are the users
  - How often is SDSS used
  - What functions of SDSS are used

In conclusion, there are three aspects of decision making - the prerequisites for decision making, the decision making process, and the decision. I have focused on the prerequisites: availability of spatial information and SDSS usability. These are the necessary ingredients that will serve as the foundation for SDSS.