Geo-Information Technology; a Matter of Integration

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1. Introduction

Geo-information technology has developed spectacularly since the pioneering work of Tomlinson and others in the 1960s. (An overview of the 'state-of-the-art' in the early 70s can be found in Tomlinson, 1972.) Seen from a technical point of view, developments are impressive as many conference proceedings convincingly show. However, many of these technical developments never leave the domains of laboratories or externally funded projects. This leads to the question of effective usability of this technology. In a survey of the effectiveness of GIS in British local government, Campbell concludes that while the successful implication of GIS is not necessarily impossible it is extremely difficult (Campbell, 1994, p 321). Nevertheless, geo-information and GIS has been adopted to a very considerable extent in government in most industrialized countries. (See, for example, for British local government: Campbell and Masser, 1995, p 83; for Dutch local and national government: Grothe and Scholten, 1996, p 238.) These findings, however, leave the question of effectiveness unanswered. The situation in less developed countries is even more problematic. For example, Linden concludes, based on a survey held in 1992 in 11 countries in Sub-Sahara Africa, that the majority of existing GIS's is hardly used or does not meet the initial expectations notwithstanding the serious need of geo-information technology because of urgent problems such as the rapid depletion of natural resources together with environmental degradation (Linden, 1996, pp 269-275). Based on a survey in several South-east Asian countries, Kammeier, concludes that actual performance of many GIS's lags behind the potential of the hardware and software already installed (Kammeier, 1996, pp 297-305).

Like all technologies, geo-information technology has two distinct components: science and engineering on the one hand, and organizational and societal challenges on the other. Often, the value of geo-information technology is understood as producer of specific sets of information supporting managerial functions like planning and decision making. However, application of geo-information technology not only provides information but links individuals as well. For example, establishing a GIS links producers and consumers of spatial data and information and makes them think about their information requirements; in fact: makes them jointly think about their jobs and activities and how to improve these. In this respect, establishing a GIS might be a form of organizational development or even institution development. (See also: Yeh, 1991, pp 24-25; De Man, 1996b, p 276.) In their quest for effective GIS implementation, Campbell and Masser emphasize the significant role of organizational culture and the ability to cope with change. In particular the importance of devising an information management strategy which identifies the core needs of users and the type of service that they require, as well as considering the resources at the disposal of the organization. Commitment and participation are also vital components of implementation (Campbell and Masser, 1995, pp 159-160). As Gar-on Yeh states it, successful implementation of GIS will depend upon a clear understanding of the function and needs of planning that are translated into system applications (Yeh, 1991, p 25).

In summary, success (or failure) in the application of geo-information technology depends on both *technical* and *non-technical* factors; the latter relating to the user and management context. It is fruitless to speculate about the predominance of one of them over the other; both are important. Without proper and sound technical design, technology will not bring us very far. But without proper societal context, technology can't bring us anywhere either. In the domain of the *technical* issues, integration of decision support systems (DSS) into geo-information technology is a not yet satisfactory resolved challenge (Kammeier, 1996, pp 297-305; Batty and Densham, 1996). In the domain of the *non-technical* issues, integration of geo-information technology within organizational and institutional processes is a hardly explored challenge (De Man, 1996a, pp 195-199; 1996b, pp 276-278) and will be coined '*institutionalization of geo-information technology*'. Consequently, geo-information technology requires *integration* in - at least - two different dimensions:

- geo-information technology and decision support systems, and
- institutionalization of geo-information technology.

2. Geo-Information Technology and Decision Support Systems (DSS)

2.1 Decision Support Systems

In our view, Decision Support Systems (DSS) are a class of information systems that support decision making processes, particularly in the cases of ill-structured problems. Their primary feature is - through access to appropriate data and models - to aid the decision maker in exploring a problem and thereby increasing the level of understanding about the decision environment. DSS are aimed at generating and evaluating alternative solutions in order to gain insight into the problems and trade-offs between various objectives, and to support the decision-making process at hand.

The primary intention of DSS is to assist specific decision makers, individually or in groups, rather than an entire organization. This allows *customer-centered design* of the system, in which decision makers can use the decision support system interactively to build and more importantly, to change analytic models of the decision problem, and which is based on the *direct involvement* of the end user in system design and development. The user's view of the problem and his or her experiences with (aspects of) the management and decision making process must be fully taken into account.

Interactive use allows immediate changes in assumed parameters with rapid feedback, encouraging a *learning process.* Therefore, interaction is a central feature of any effective man-machine-system. Real-time dialogue allows the user to define and explore a problem in response to immediate answers from the system. Fast and powerful systems offer the possibility to simulate dynamic processes and provide a high degree of responsiveness that is essential to maintain a successful dialogue and to have direct control over the software.

Decision support paradigms may include *predictive* models, which give unique answers but with limited accuracy and validity. Scenario analysis relaxes the initial assumptions by making them more conditional, but at the same time more dubious. *Normative* models prescribe how things should happen, based on theory, and generally involve optimization or game theory. Alternatively, *descriptive* or behavioral models describe things as they are, often with the exploitation of statistical techniques.

Prescriptive analysis of decisions emphasizes the development, evaluation and application of techniques to facilitate decision making. These studies rely upon the logic of mathematics and utilize the concepts of utility and probability to analyze decision problems. The concept of utility relates to the expression of preferences of alternative options, whereas probability serves to evaluate the likelihood of these preferences being utilized.

Traditionally, prescriptive decision analysis has the form of either an objective or subjective evaluation of decision criteria. In *objective analysis*, attempts are made to provide a functional appraisal of a decision event by identifying all potential effects and the magnitude of impacts based on market values. The net value of the benefits of possible alternative choices are then compared with the costs associated with the choice (cost benefit analysis). *Subjective analysis* of decision events on the other hand, comprises various approaches that share the common purpose of helping decision makers to express consistent judgment and choose rationally.

The techniques adopted in the various approaches incorporate explicit statements of preferences of decision makers. Such preferences are represented by various quantities, weighting schemes, constraints, goals, utilities, and other parameters. They analyze and support decisions through formal analysis of alternative options, their attributes vis-à-vis evaluation criteria, goals or objectives, and constraints. DSS functions range from information retrieval and display, filtering and pattern recognition, extrapolation, various applications of multiattribute utility theory, optimization, inference and logical comparison to complex modeling.
For improved decision making, all tools and models have to become integrated in an information processing and decision making procedure, which involves running the models, capturing and preparing its inputs (over and over again), interpreting and communicating its results, and making them fit in the existing procedures.

With respect to *spatial problems*, decision support relies heavily on our ability to spatial representation and visualization. Research on mental imagery indicates that images are used to remember facts about objects and events, (Kosslyn, 1983). It is estimated that 50 percent of the brain's neurons are associated with vision (McCormic et al, 1987); image presentation can help communicating large amounts of information quickly and is a very important and powerful characteristic. The ability of the brain to comprehend and take-in information is estimated to be about 2 giga-bits per second (Mundie, 1989). Visualization provides the bandwidth necessary to understand large amounts of highly structured information and development of an intuitive understanding of processes and interdependencies of spatial and temporal patterns, and of complex systems in general.

2.2 Spatial Data Analysis

"Spatial Analysis" can be defined as a wide range of analytic techniques applied to spatial objects, including processes to create new classes of spatial objects, to analyse the locations and attributes of objects, and to model using multiple classes of objects and the relationships between them. It includes primitive geometric operations such as calculating the centroids of polygons, or building buffers around lines, as well as more complex operations such as determining the shortest path through a network (Goodchild, 1992, p 38). An added objective of spatial analysis is to solve scientific or management decision-problem.

In their conceptual GIS model, Anseline and Getis (1992) identify four groups of analytical functions; selection, manipulation, exploration and confirmation. *Selection* involves the query or extraction of data from thematic or spatial databases. *Manipulation* entails transformation, partitioning, generalization, aggregation, overlay and interpolation procedures. Selection and manipulation in combination with visualization can be powerful tools for spatial analysis. *Data exploration* encompasses those methods that try to obtain insight into trends, patterns and associations in data without having a preconceived theoretical notion about which relations are to be expected (Tukey, 1977; Anseline and Getis, 1992). This data driven exploratory approach is considered to be very promising, because in many disciplines theory in general is poor and spatial data is becoming increasingly available. *Confirmative analysis* is based on a priori hypothesis of spatial relations that are expected and formulated in theories, models and statistical relations (technique driven). Confirmative spatial methods and techniques originate from different disciplines like operation research, social geography, econometry models and environmental sciences.

These four analytical functions can be considered as a logical sequence of spatial analysis. Further integration of maps and (other) results from spatial analysis is an important next step to support decision making. Lack of functionality especially in exploitative and confirmative analysis in GIS packages is increasingly felt as a major obstacle to their effective utilization. As a result, techniques to support these steps are gaining attention nowadays. Several studies have demonstrated the usefulness of integrating multi-objective decision techniques with GIS, and vendors have incorporated some analytical techniques in their GIS packages (like for instance IDRISI and ESRI).

2.3 Decision Support Systems and Geographic Information Systems

With the development of GIS, environmental and natural resource managers increasingly have at their disposal information systems in which spatial data are more readily accessible, more easily combined and more flexibly modified to meet the needs of environmental and natural resource decision making. It is thus reasonable to expect a better informed, more explicitly reasoned, decision making process. But despite the proliferation of GIS software systems and the surge of public interest in the application of such systems to resolve real world problems, the technology is commonly seen as complex, inaccessible, and alienating to the decision makers (Fedra, 1993).

The reasons for this estrangement are varied. The early development and commercial success of GIS were in part fuelled by a need for efficient spatial inventory rather than by a direct need for decision support. As a result, few systems provide any explicit decision analysis tools as yet. Moreover, the technology is built upon a very broad base of scientific disciplines, including cartography, remote sensing, computer science and statistics. This implies that to become well introduced to the used GIS, a solid background in digital data management, mapping sciences and information technology is required. Geo-information technology has elements of modernity and scientific rigor that are strongly cultivated by vendors, consultants, and other advocates. As a result, GIS has become a field requiring a host of *intermediaries* between the data provider and the end user; for instance: technicians, system managers, analysts, user interfaces, query languages and so on.

The lack of analytical tools to efficiently aid decision evaluation and policy formulation and the continuing mystification of modern geo-information technology have all contributed to sub-optimal utilization. As a result, GIS has become a rifting technology, tending to divert the process of decision making away from decision makers and into the hands of GIS analysts and a host of other highly trained technological intercessors (Eastman, et al. 1993).

To alleviate the above problems, GIS should be upgraded by the DSS functionality in a user driven and user-friendly environment. Evidently, there is a trade-off between the efficiency and ease of use on the one hand, and the flexibility of the system on the other. The more options that are predetermined and available from a menu of choices, the more defaults are provided. There is also a trade-off between the ease of understanding and the precision of the results. For example, providing a visual or symbolic presentation of spatial facts and phenomena may enhance the ease of understanding but at the expense of precise, quantitative results. Finally, the easier the system is, the harder it is to make and to maintain such system.

Policy analysis and policy formulation requires simulation modeling (descriptive models) and substantial insight into the decision behavior of individual actors. Once a policy is adopted, the decision-making problem is one of choosing between a number of specific resource allocation options. The techniques of *multiple criteria and multiple objective evaluation* are well suited for problems of this nature. However, the application of these techniques within a GIS-environment is still in its infancy and their use is not widely recognized for a broader spectrum of decisions (for example: policy selection versus resource allocation)

Group decision support systems facilitate the exchange of ideas (brainstorming), stimulating members to participate, and organizing collective thought into a workable consensus. In this context a set of *participatory* multiple criteria and multiobjective evaluation techniques are needed that aim to place the GIS analyst as a mediator between the computer technology package and the decision makers. Here GIS can be seen as a vehicle for problem solving and decision making by accommodating the variety of stakeholders in the decision making process.

2.4 Spatial Decision Support Systems

The recognition that many problems do have a spatial dimension has stimulated in the past decade the merging of GIS and DSS functionalities into a powerful combination that became known as ‘Spatial Decision Support System (SDSS)’. It aims at providing the user with a decision making environment that enables the analysis of geographical information in a flexible manner. Such systems require some additional capabilities to be added to the conventional (non-spatial) DSS such as (Douven, 1997):

- provisions for the input of spatial data;
- representation of complex spatial relations and structures that are common in spatial data;
- analytical techniques that are applied in spatial and thematic analysis;
- provisions for output in a variety of spatial forms.

According to Densham and Goodchild (1989), SDSS should incorporate knowledge used by expert analysts to guide the formulation of the problem, the articulation of desired characteristics of the solution, and the design and execution of the solution process. However, in spite of ample discussions in the literature on the integration of DSS and GIS, not very many SDSS have actually been developed (Grothe et al. 1996).

2.5 Integration of GIS and DSS

Integration of GIS and DSS, in combination with simulation and optimization models, relational databases, and expert-system tools, aims at making decision support tools attractive and user-friendly for a large spectrum of planning and management problems.

The research community especially has sought ways to enhance the analytical capability of GIS, through integration of spatial data handling, modeling and decision support functionality to support management functions. Various logical ways of coupling GIS and disciplinary models are discussed in literature (Fedra, 1993). A division can be made between:

- *loose coupling*; GIS and models communicate through exchange of files. It is normally time consuming and prone to error;
- *close coupling*; GIS and models are connected through a common user interface which is taking care of the data sharing between the two systems;
- *tight coupling*, GIS and the models are merged into one system. Models become an analytical capability of GIS.

Goodchild (1993), states that the needs are best handled not by integrating all forms of geographic analysis in one package but by providing appropriate linkages and hooks to allow software components *to act in a federation*. The advantage of such approach is that different integration of functionality groups can take place serving different user needs. Moreover the integration can be guided more by functional than technological considerations, as it takes place irrespective of hard- and software used. To achieve this, a greater degree of openness of spatial data formats is required (so-called ‘Open Geo-data Interoperability Specification’ - OGIS). In this connection one of the tasks is the identification of a generic GIS functionality and services (Mularz et al. (1995). Such an approach comes close to the conceptual design of DSS given by Sprague (1980), who identifies three technological levels for DSS development: (1) Specific DSS, (2) DSS generator and (3) DSS tools. Developments in the context of OGIS will complement the DSS toolbox with generic spatial data handling functionality and thus facilitate the development of SDSS.

3. Institutionalization of Geo-Information Technology

We shall now turn to the domain of the non-technical issues; *viz.* the user and management context of geo-information technology. Ultimately, the value of geo-information technology (like any other technology for that matter) arises out of its *use*. In the following, we will first argue that meaningful application of information technology is fundamentally a *social process*. Consequently, concrete applications of geo-information technology are linked with other social processes, in particular, with other informational processes. Second, technologies such as geo-information technology are distinguished by the propensity for organizations rather than individuals to provide the focus for decisions concerning diffusion (Campbell and Masser, 1995, p 9). Therefore, *an organizational perspective* would be needed in geo-information technology. Third, geo-information technology aims at linking spatial knowledge and (organized) action. What then, causes collective action? We will argue that geo-information technology *as an institution* may contribute to this. Finally, *participation* in either of the stages of collection, analysis, and processing of spatial data, and presentation of the resulting information, may be a major factor for geo-information technology to become collectively valued and institutionalized.

3.1 Application of Geo-Information Technology as a Social Process

From the outset, we view information not only as a *product* but as a *process* as well. Information is seen as a product resulting from the processing of (raw) data to answer a question. Information-as-a-process can be viewed at three different levels. The *first* level of information-as-a-process is the domain of geo-information technology in its narrow, technical sense; how to process data into information. Or, rather, how to process data into other data. Because *how data acquire meaning* - and thus provide an answer to a question - is not (fully) explained at this level. An alternative view sees information as an interpretative process of giving meaning to observable facts through the collection and analysis of data about these facts. (See for example, also: Bonnen, 1975.) The *second* level of information-as-a-process is the level of individual human perceptive, psychological, and cognitive processes. Individual users' needs are studied at this level. However, users generally act and interact in groups. Consequently, most users' needs must be studied within a social rather than a pure by individual context. In addition, so-called 'Symbolic Interactionism' sees the process of giving meaning as a fundamentally *social process* (Blumer, 1969). This, then, is the *third* level of information-as-a-process; the level of (complex) groups or societies.

3.2 Information Utilization System

Groups or societies rely entirely on communication. For communication is essential to collective and cooperative behavior. The whole of the data and information flows, their channels, creators, collectors, users, and so on, oriented towards (end-) uses within groups or society, may be referred to as the '*information utilization system*' (De Man, 1988). It may take the form of all sorts of existing and indigenous - and therefore mostly informal - knowledge and communication systems. One step further brings us to the understanding that meaningful applications of any information technology - like, for instance, a GIS - have to fit within or add to an *existing* information utilization system. In the final analysis, the (potential) application of (geo-) information technology must be considered against the background of the (existing) information utilization system. More specifically; whether this application is *functional* and supportive with respect to the information utilization system in which it is embedded. This, then, leads to the question whether *geo-information technology allows and contributes to the integration with other (often: existing) data and information.*

3.3 Geo-Information Technology; a Problem of Organization

Geo-information technology is generally applied within more or less organized groups of human beings. It has the potential

- to facilitate *communication* between organizational members (units and individuals);
- to help *link* organizational units and individuals functionally and operationally together; and
- to be a *tool* to enhance the organization's ability to achieve organizational goals and tasks (*viz.* through the provision of information).

Many organizations face the need for frequent - if not continuous - adaptation to uncertain and changing environments. In other words, organizations need to learn. Moreover: organizations need to *learn to learn* (see also: Morgan, 1986). Consequently, the identification of information requirements for spatial problem solving (like spatial analysis, spatial planning and decision making, implementation of these plans, and environmental monitoring and management) becomes non-trivial. In addition, geo-information technology may have an impact on the structure and design of the organization, and on its occupational structures and functions. Hence, the question *whether geo-information technology is supportive or a barrier for organizational learning and adaptation*.

3.4 Institutionalization; a Normative Impact on Problem Perceptions and Collective Actions

In GIS literature, the term 'institutional' is generally used to *conditions* for effective implementation and utilization. (See, for example: Fox, 1991.) But geo-information technology (and its resulting geo-information) *itself* may become institutionalized in that it is being collectively valued and having a normative impact within a group or society on the creation of *common perceptions of spatial problems*. We view an 'institution' as a rather stable cluster of norms and normative behaviors, that develops around a basic social need (see also: Robertson, 1982, p 93). Institutionalization of geo-information technology then relates to the need to collectively address spatial problems. Common perceptions of problems, in turn, are prerequisites for concerted and collective actions to remedy them. We suppose that common perceptions of problems that are created in this way, cause or stimulate collective actions. This, then, leads to the question *under what conditions geo-information technology is to bring about (1) the creation of common perceptions of spatial problems and, subsequently, (2) collective actions to remedy them*.

3.5 Participation as a Factor for Institutionalization

Information may become valued within a community through *participation* in the collection and subsequent analysis of data about the own situation. This may bring about that these observed facts become an effective basis for change and improvement. We may expand this argument by asserting that geo-information technology becomes valued through participation in its design, choice and implementation (see also: Campbell and Masser, 1995, pp 159-160). Participation, then, might be a major factor in the process of institutionalization of geo-information technology. This leads to the question regarding *conditions for participation in the design, choice and implementation of geo-information technology*.

4. References

Anseline, L. and Getis (1992). ‘Spatial statistical analysis and geographic information systems’, in: Fisher, M.M. and Nijkamp, P. (eds), *Geographic information systems, spatial modelling and policy evaluation*, Springer Verlag, Berlin.

Batty, Michael and Densham, Paul J. (1996). *Decision support, GIS, and urban planning*, Centre for Advanced Spatial analysis, University College London, London.

Blumer, H. (1969). *Symbolic interactionism: perspective and method*, Prentice-Hall, Englewood Cliffs, N.J..

Bonnen, James T. (1975). ‘Improving Information on Agriculture and Rural Life’, *American Journal of Agricultural Economics*, **57**, (Dec.) 753-763.

Campbell, Heather (1994). ‘How effective are GIS in practice? A case study of British local government’, *Int. Journal of Geographical Information Systems*, **8**, 309-325.

Campbell, Heather and Masser, Ian (1995). *GIS and Organizations*, Taylor & Francis, London.

De Man, W.H. Erik (1988). ‘Establishing a Geographic Information System in Relation to its Use: a Process of Strategic Choices’, *Int. Journal of Geographical Information Systems*, **2**, 245-261.

De Man, W.H. Erik (1996a). ‘Geographic Information Technology in Support of Local-level Planning and Decision Making. (Challenges and Opportunities for Southeast Asia)’, in: Tung, F. *et al* (eds), *GIS in Asia*, GIS Asia Pacific, Singapore.

De Man, W.H. Erik (1996b). ‘Establishing geographic information systems as institution building’, in: Meulen, George G. van der and Erkelens, Peter A. (eds), *Urban Habitat: the environment of tomorrow*, Fac. of Architecture, Eindhoven University of Technology, Eindhoven.

Densham, P.J. and Goodchild, M.F. (1989). ‘Spatial decision support systems: a research agenda’, in: *Proceedings GIS/LIS 1989*, Orlando, Fl..

Douven, W.J.A.M. (1997). Improving the accessibility of spatial information for environmental management.

Eastman, J.R., Kyek, P.A.K. and Toledano J. (1993). ‘A procedure for multiobjective decision making in GIS under conditions of conflicting objectives’, in: *Proceedings of the EGIS 1993 Conference*, Genova, (Italy).

Fedra, K. (1993). ‘GIS and environmental modelling’, in: Goodchild, M.F., Park B.O. and Steyaert, L.T. (eds), *Environmental modelling with GIS*, Oxford University Press, New York.

Fox, Jefferson Metz (1991). ‘Spatial information for resources management in Asia: a review of institutional issues’, *Int. Journal of Geographical Information Systems*, **5**, 59-72.

Goodchild, Michael F. (1992). ‘Geographic information science’, *Int. Journal of Geographical Information Systems*, **6**, 31-45.

Goodchild, M.F. (1993). ‘The state of GIS for environmental problem-solving’, in: Goodchild, M.F., Park B.O. and Steyaert, L.T. (eds), *Environmental modelling with GIS*, Oxford University Press, New York.

Grothe, Michel and Scholten, Henk J. (1996). *GIS in de publieke sector* (in Dutch; ‘GIS in the public sector’), Netherlands Geographic Studies nr. 204, Koninklijk Nederlands Aardrijkskundig Genootschap, Utrecht.

Kammeier, H. Detlef (1996). ‘The needs for computer-aided information and decision-making techniques for urban and regional planning in Asian developing countries’, in: Meulen, George G. van der and Erkelens, Peter A. (eds), *Urban Habitat: the environment of tomorrow*, Fac. of Architecture, Eindhoven University of Technology, Eindhoven.

Kosslyn, S.M. (1983). Ghosts in Minds Machine: Creating and Using Images in the Brain, Norton, New York.

Linden, G. (1996). ‘Information technology for development’, in: Meulen, George G. van der and Erkelens, Peter A. (eds), *Urban Habitat: the environment of tomorrow*, Fac. of Architecture, Eindhoven University of Technology, Eindhoven.

McCormic, B.H., Defanti, T.A. and Brown M.D. (1987). ‘Visualization in scientific computing - a synopsis’, *IEEE Computer Graphics and Application*, **7** (7), pp 61-70.

Morgan, G. (1986). *Images of organization*, Sage, Beverly Hills, Cal..

Mularz, D.E., Smith, H.G. and Wobray, T.J. (1995). 'Realizing the NSDI-vision through community architecture', *Geo-information systems*, January.

Mundie, C. (1989). 'Interacting with the tiny and the immense', *Byte*, **14** (4), pp 279-288.

Robertson, Ian (1982). *Sociology*, Worth, New York.

Sprague, R.H. (1980). 'A framework for development of decision support systems', *Management information science, quarterly*, **4**, pp 1-26.

Tomlinson, Roger F. (1972). *Geographic data handling* (2 volumes), IGU Commission on Geographical Data Sensing and Processing, Ottawa.

Tukey, J.W. (1977). *Exploratory spatial data analysis*, Adison Wesley, Boston.

Yeh, Anthony Gar-on (1991). 'The development and application of geographic information systems for urban and regional planning in developing countries', *Int. Journal of Geographical Information Systems*, **5**, 5-27.