Geographic Information Systems as Decision Tools

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INTRODUCTION

Geographic information systems (GISs) as a technology have been studied and reported extensively and, not unexpectedly, in the field of geography. The various ways of capturing spatial data, arranging attribute data into appropriate database structures, and making the resulting large data sets efficient to store and query have been extensively researched and reported (Densham, 1991). However, the geographic research community has only recently noted the need to study how GISs are used as decision tools, especially with regard to how such decision making might be related to a decision maker's cognitive style (Mennecke, Crossland, et al., 2000). As an example, the University Consortium for Geographic Information Science called for research examining how geographic knowledge is acquired through different media and by users with different levels of experience and training (University Consortium for Geographic Information Science, 1996).

Researchers in the fields of decision sciences and information systems have more recently begun to make contributions in the area of decision making with GISs. When a GIS is employed as a decision support system, in these studies the resultant system is often referred to as a *spatial decision support system,* or *SDSS* (see Crossland, 1992; Crossland, Perkins, et al., 1995; Mennecke et al., 2000).

A *geographic information system* in its simplest form is a marriage of accurately scaled digital maps with a database. The digital maps comprise spatially referenced details such as natural elements (lakes, rivers, topographic elevation contours, etc.), manmade objects (buildings, roads, pipelines, etc.), and political boundaries (city limits, state and county lines, international boundaries, etc.). These natural elements are typically referenced, with varying degrees of precision, to latitude/longitude coordinates on the earth's surface. It must be noted here that the degree of precision and, more importantly, differences in degrees of precision for the various elements are the subjects of much research and user consternation in applications of GISs to solving problems. The database, in turn, catalogs information about the various spatial elements (e.g., the names of rivers, names of buildings, building owner, operator of a pipeline, etc.). These descriptive entries in the database are often referred to as *attributes* of the various spatial elements.

A GIS may be paired with the *global positioning system* (*GPS*), from which real-time, satellite-derived location information may be derived, as provided by an appropriate GPS receiver.

BACKGROUND

With regard to the effectiveness of decision making when using information tools, there is a relatively long history of researchers emphasizing that tools which provide graphical presentations and graphical representations of information are deserving of special note and study. For example, Ives (1982) discussed at great length the role of graphics in business information systems. He even went so far as to state, "The map, perhaps more than any other chart form, gains the most from the availability of computer graphics" (p. 16).

Several more recent studies have drawn from Image theory (Bertin, 1983) to help explain why decision makers using GISs may experience greater effectiveness in decision making. Image theory states that one graphical representation of information may be considered more efficient than another for a particular question, if that question can be answered in the mind of the decision maker in a lesser amount of time. In his *Semiology of Graphics*, Bertin defined image theory and put forth the constructs of images and figurations. An *image* is a meaningful visual form, perceptible in a minimum instant of vision. A *figuration* is a more complex construction comprising multiple images. Figurations are inherently less efficient than images, according to image theory. This is because the viewer is able to grasp the full informational content of an image in a brief moment of viewing it. Figurations, on the other hand, comprise multiple images which must be mentally extracted, processed, and related in the viewer's perception. Although the informational content may be richer in a figuration, it is inherently less efficient for quick extraction of specific information.

The more recent studies propose that one role of GISs is to collapse more complex figurations into simpler figurations or even to simple images. This has the net effect of increasing a decision maker's efficiency in extracting relevant information for the purpose of evaluating and making a decision. For examples the reader is encouraged to review Crossland

(1992), Crossland, Herschel, et al. (2000), Crossland et al. (1995), and Mennecke et al. (2000).

Although there seems to be a common assumption that GISs improve decision making (Morrison, 1994), only a few studies to date have performed controlled experiments to actually test this assumption. Those that have been accomplished typically used dependent variables of decision time and decision accuracy to measure decision-making effectiveness. These include Crossland (1992), Dennis and Carte (1998), Mennecke et al. (2000), Smelcer and Carmel (1997), and Swink and Speier (1999). All of these studies found that the addition of a GIS to a spatially referenced decision-making task had a positive effect on decision outcomes.

THE ROLE OF COGNITIVE STYLE IN DECISION MAKING WITH GISS

With respect to decision making, the term *cognitive style* has been used to refer to enduring patterns of an individual's cognitive functioning that remain stable across varied situations. Various elements of cognitive style have been speculated upon and studied in various disciplines. With respect to decision making using GISs, two elements have been studied in some depth, *field dependence* and *need for cognition*.

Field dependence (FD) measures a person's ability to separate an item from an organized field or to overcome an embedded context (Witkin, Lewis, et al., 1954). Zmud and Moffie (1983) proposed that people with lower field dependence tend to outperform those with higher field dependence in structured decision tasks and that they tend to make more effective use of transformed information (e.g., aggregated values and graphical formats, such as are typically found in a GIS). FD can be measured using commercially available testing instruments. Because making decisions using a GIS, by its nature, involves mentally extracting relevant information from a potentially complex field of information, studies have hypothesized that low field dependence should predict better decision making with a GIS or other spatially referenced tool. In particular, field dependence is seen as an inverse proxy for an individual's level of spatial cognition—the ability of an individual to grasp and analyze information within a spatial context.

Need for cognition (NFC) was proposed by Caccioppo and Petty (1982) as a measure of a person's internal motivation to pursue and enjoy cognitive tasks and activities. They developed a questionnaire which can be used to measure this cognitive-style attribute. People who score high on the need for cognition scale tend to enjoy the engagement of thought activity in a task as much or more than even the result of a task. The studies named below hypothesized that this tendency to engage more fully in a task should lead to more effective decision making, as measured by the dependent variables of decision time and decision accuracy.

Studies that looked at FD, NFC, or both as independent variables of decision-making performance using GISs include Crossland (1992), Crossland et al. (1995), and Mennecke et al. (2000). In general, the findings may be summarized as follows:

- Field dependence exhibits an inverse main effect on decision time, but not on decision accuracy. That is, subjects with lower field dependence tend to solve spatially referenced problems more quickly, but not more accurately. It may be that the efficiency predicted by image theory does contribute to faster decision making, but not to more accurate decisions.
- Need for cognition exhibits a positive main effect on decision accuracy, but not on decision time. That is, higher-NFC subjects tend to solve spatially referenced problems more accurately, but not more quickly. This last finding was noted as unexpected by Crossland (1992). He speculated that perhaps an individual with a high NFC might tend to spend longer in thinking about the problem and its solution, thereby extending the decision time. It would seem, however, that this extra thinking effort may have contributed to a more accurate solution.

FUTURE TRENDS

Some questions and issues in this area of research that remain to be addressed include:

- How do other important measures of cognitive style affect a decision maker's ability to solve spatially referenced problems accurately and quickly?
- How does problem complexity factor in or even interact with the decision maker's task? Several studies also examined problem complexity as an independent variable (Crossland, 1992; Crossland et al., 1995; Mennecke et al., 2000). Crossland et al. (1995) reported an observed interaction of field dependence with problem complexity that would be interesting to explore further.
- To what extent are SDSSs/GISs effective in collapsing figurations (as defined by image theory) into images or into simpler figurations? Are there certain levels of complexity beyond which it becomes impractical or ineffective to combine or collapse displays into simpler decision tools? How does the cognitive style of the decision maker factor into this consideration?
- Are SDSSs/GISs even necessary for certain types of problems? Perhaps a series of static, hard-copy outputs are sufficient for some decisions by some decision makers, and the combined or flattened displays are not