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Individual decision-maker performance with and without a geographic information system: An empirical investigation

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INDIVIDUAL DECISION-MAKER PERFORMANCE WITH AND WITHOUT A GEOGRAPHIC INFORMATION SYSTEM: AN EMPIRICAL INVESTIGATION

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ABSTRACT

This study utilized a laboratory experiment to investigate the effects on decision-maker performance of using a geographic information system (GIS) as a decision support aid. GIS are increasingly being used for decision-making, yet research about their contributions to the performance of decision-makers has been lacking. This study makes a contribution to that apparent void.

Volunteer subjects completed a site location task that required decisions to be made based upon spatially referenced information. Performance was operationalized as elapsed time and accuracy. The task environment was manipulated in two dimensions. In one dimension, task complexity was varied on two levels. In the other dimension, some subjects were provided a geographic information system as a decision aid, and the rest were not. Two aspects of individual cognitive style, field dependence and need for cognition, were measured pretask and factored into the analysis.

Significant differences were found between task solutions developed by GIS users and those developed by non-GIS users. GIS users experienced shorter solution times and fewer errors for both levels of task complexity. People with high field dependence experienced longer solution times than those with less field dependence, and people with high need for cognition experienced a lower accuracy than those with less need for cognition.

The study builds upon and extends image theory as a basis for explaining efficiency differences resulting from different graphical displays of spatial information.

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CHAPTER 1: INTRODUCTION

Geographic information systems (GIS) technology is both a rapidly-growing industry and a significant new approach to data management and analysis. A recent multivendor-sponsored, ten-page advertising supplement in *Business Week* (1991) proclaimed the importance of GIS in its headline:

> There's a quiet revolution going on. It's a revolution that impacts each of our lives, although few of us have heard anything about it yet.

The industry and the research community have not yet developed a standard definition of GIS. One definition which has been incorporated into at least one new GIS textbook (Antenucci, Brown, Croswell, and Kevany, 1991) has been proposed by Hanigan (1988), who defines a GIS as:

> any information management system which can:
>
> ✓ Collect, store, and retrieve information based on its spatial location
>
> ✓ Identify locations within a targeted environment which meet specific criteria
>
> ✓ Explore relationships among data sets within that environment
>
> ✓ Analyze the related data spatially as an aid to making decisions about that environment

✓ Facilitate selecting and passing data to application-specific analytical models capable of assessing the impact of alternatives on the chosen environment

✓ Display the selected environment both graphically and numerically either before or after analysis.

It is within the context of this definition that this study was formulated and grounded.

Researchers investigating various types of information systems (IS) have often been concerned about the value of IS. However, results have been mixed with regard to assessment of IS value. One facet of this effort has been the study of contributions of IS to overall organizational performance. Lucas (1975), for example, found only weak association between performance of organizations and usage of IS by members of those organizations. King and Rodriguez (1978) likewise reported somewhat disappointing results in a study where they found that the "system which was the focus of this study was not evaluated as highly as might have been hoped for by its developers, which is likely to be the case in most MIS evaluation efforts." A general consensus might be inferred from the literature that many MIS implementations have failed to provide the incremental value intended by their developers, at least at the organizational level. Therefore, it has become important to demonstrate positive expected values associated with new systems prior to their design and implementation.

A significant amount of IS research effort has also been invested in the area of Decision Support Systems (DSS), including the value added by DSS usage. Money, Tromp, and Wegner (1988) suggested that the benefits of DSS usage might be divided into three groups: (1) those at the managerial level, (2) those at the operational level, and (3) those at the personal (individual user) level. The results of their study showed that users attached significantly greater importance to the personal level of benefits than to nonpersonal level benefits. If we assume that improving individual decision-maker performance is a personal-level benefit we might ascribe to a DSS, then it is worthwhile to consider to what degree any DSS, including a GIS, makes such a contribution. The problem and questions investigated here involved an assessment of the value, at the individual level, of using GIS technology as a decision support system.

A cursory review of GIS may leave the reviewer with the impression that it is simply another method of displaying information graphically, although in reality it is much more. Researchers have spent considerable effort in examining value contributions and the effects on decision-makers of varying the mode of information presentation. For example, experimental studies by Benbasat & Dexter (1985 and 1986), Benbasat, Dexter, & Todd (1986a, 1986b), Liberatore, Titus, & Dixon (1988), Yoo (1985), Davis (1986 and 1989), Lauer (1986), Hoadley (1988 and 1990), Addo (1989), Joyner (1989), and others have investigated the effects of color, complexity and form of information presentation on information extraction and decision-making. However, each of these studies was limited to investigations involving tabular information and various types of business graphs -- line graphs, bar charts, pie charts, etc. An area of graphical information processing and usage which has largely been ignored is the graphical analysis of spatial information, or more specifically, computer graphic maps.

Because GIS technology provides an important way to enable such graphical analysis of spatial information, and also because the study of GIS has been ignored in IS research to date, the following problem exists with the current state of IS research:

> IS research has not adequately assessed the potential contributions of GIS technology to organizational or individual decision-making.

GIS applications and usage are likely to continue to proliferate, and related research should grow as well. This study contributes to the body of knowledge about GIS in an IS context, and provides findings which support further research about the use of GIS as a decision support aid.

The primary question in this research

For various implementations of IS and, more generally, most types of computer systems, questions are almost always asked by those who must pay for them regarding the benefits of the new systems. GIS is no different from traditional IS in this regard.

A type of research question commonly asked in the computer graphics research cited earlier might be stated as: Do decision-makers make different decisions with different types of information displays? More specifically and perhaps more pertinent, one might ask which types of displays enable decision-makers to make *better* decisions?

As has been pointed out earlier, GIS is not simply another alternative data display tool. It is a comprehensive set of tools for collecting, storing, retrieving, analyzing, and displaying spatially referenced information. While a GIS typically includes various graphical display capabilities as part of its analytical tool kit, it is not limited to them. A typical fully-featured GIS includes a wide array of data analysis and display tools.

Commonly-available GIS features included in the experiment in this study are map overlays, thematic mapping, and area buffering. Map overlays are the capability to simultaneously display multiple "layers" of information which are common to a given location. Thematic mapping allows selective shading or coloring of areas or individual items on a map according to values contained in a linked database. Area buffering enables the user to answer, through selective coloring, shading, or highlighting, such proximity questions as, "Where are items or occurrences of a certain type that are located within a given radius of a certain location?"

As an extension of the question from graphics research just stated above, the primary question addressed by this study is:

> Does the addition of GIS technology to a decision-making environment affect the performance of the individual decision-maker when the decision task involves spatially referenced information?

Importance of the topic

This study contributes to the body of IS research by assessing the contributions made by the addition of GIS technology to a decision-making environment which includes spatially referenced information. It may be important to organizations that are contemplating investments in GIS technology to help them assess the potential benefits of such investments.

Importance to IS research

A number of prior IS research efforts in computer graphics have reported mixed results, and many cite the need for related and supporting research (DeSanctis, 1984). DeSanctis (1984) mentions that empirical research on the use of maps in general (that is, paper-based or computer-based) is minimal, but that the little that is available is relevant to the study of visual aids, including graphics. Some of these studies have dealt with communication effectiveness of map characteristics -- such as symbology, color, and display size -- in map design (Castner & Robinson, 1969; Shontz, Trumm, & Williams, 1971). However, few if any of these studies have dealt with decision-making as it relates directly to maps, particularly in the area of business decision-making.

Some studies have dealt implicitly with spatially referenced tasks without actually using maps. For example, Jarvenpaa (1989) used laboratory experimentation to investigate the effect of task demands and graphical format on a spatially referenced task *without* using a graphical representation of the spatial nature of the problem. Specific attributes of various alternative store locations were presented to experiment participants in "business graphic" bar charts, and decisions were elicited. One significant outcome from this experiment was the suggestion that future graphics research should evaluate decision accuracy and decision time jointly. This study incorporated this suggestion as a major premise.

Ives (1982) stated the urgency of this general type of investigation regarding decision-making with computer graphics:

> The most urgent area of research that must be addressed is the demonstration of decision-maker productivity improvements attributable to the use of computer graphics. Studies attempting to compare tabular and graphical presentations have frequently been poorly designed and produce equivocal findings. Additional studies must be conducted, preferably in both lab and field settings. These should be designed to compare differences among individual decision-makers, and more importantly, the characteristics of the tasks facing the decision-maker.

This study provides some of the needed research in the manner so clearly called for by Ives (1982).

In a very interesting *Harvard Business Review* article heralding "The new promise of computer graphics," Takeuchi and Schmidt (1980) recognized the great potential for managers and decision-makers which would be afforded by future computer graphics applications. However, rather than a discussion of the various types of charts and graphs which would soon be available to decision-makers, practically every example cited and illustrated in that article is related to spatial analysis, geography, location selection, and other types of location-based (i.e., map-based) tasks. This piece, while somewhat prophetic with regard to present day applications of GIS, for the most part has been ignored both in citation and in spirit as a springboard for new IS research.

A notable exception to the above assertion about the ignorance of (or perhaps simply neglect of) map-based tasks in the IS research community is found in Ives (1982). In a comparison of the various forms of applications of computer graphics in business (even citing the Takeuchi and Schmidt, 1980 paper), Ives (1982) asserted:

> The map, perhaps more than any other chart form, gains the most from the availability of computer graphics. The time to manually produce maps has restricted their use to a limited set of well-funded applications. Computer generated maps can be developed in a fraction of the time, and quickly updated to reflect changes in boundaries or represented data.

One might also infer that the decision-maker utilizing the computer graphics map would also "benefit most from the availability of computer graphics." However, even with the above assertion appearing years ago in a special edition of a major IS journal, research in GIS within the traditional IS community has been practically nil. This study helps fill this apparent vacuum in the body of IS knowledge.

Importance to practitioners

It may be inferred from the preceding discussion that practitioners have had to make important economic decisions without the aid of needed basic research in the area of GIS-aided decision-making. Deyo (1991) cites figures from Daratech of Cambridge, Massachusetts which estimates total GIS-related software and hardware expenditures for 1989 totaled well over half a billion dollars. Daratech further estimates an annual growth rate of 25 percent through 1994. In an article in *Fortune*, Bylinsky (1989) declared GIS one of the fastest-growing branches of computing.

Nelson (1991) of Andersen Consulting and Perkins (1991) of International Business Machines have both described how GIS will be significant change agents for many types of organizations in the coming decade. There are increasing indications that GIS will be integrated with existing IS and that it will become part of enterprise-wide IS and DSS (Antenucci, et al. 1991). But there has been little effort expended by IS researchers in the study and evaluation of this new technology and how it might impact existing and future IS and DSS.

This study makes a significant contribution to IS and GIS practitioners who may be evaluating potential benefits of GIS implementation, including how GIS can be applied to traditional DSS problems.

Organization of the dissertation

Chapter 2 is a literature review of the four major areas of research which must be considered for a GIS study such as this: GIS research, graphics and human-computer interaction research, decision support systems research, and cognitive psychology research. Significant prior works from these four areas are related to the question asked by the present study and shown to be relevant to the study of decision-making with GIS.

Chapter 3 presents the eight hypotheses posed by the research, and then outlines the research design and methodology employed in the laboratory experiment. A number of custom computer programs were developed to aid data collection and analysis in this experiment, and these are briefly described in this chapter.

Chapter 4 details the statistical analysis techniques employed to evaluate the data collected in the laboratory experiment. Analysis techniques used included analysis of variance and independent sample t-tests of means. The appropriateness of each technique for this study is presented, along with how the data fits the assumptions necessary for each statistical tool.

Chapter 5 presents a discussion and conclusions of the study. The study is compared with similar studies conducted by other researchers, and probable reasons for the observed similarities and differences are presented and discussed. Conclusions drawn from the study in each of the four main areas of investigation are presented and supported. Finally, future directions of the research program are outlined.

The appendices are fairly extensive, and include the questionnaires administered to the experiment participants, the problem information packets for both levels of technology availability and both levels of problem complexity, and the GIS computer screens used by about half of the subjects. The two experimenter scripts are also presented in the appendices.

CHAPTER 2: LITERATURE REVIEW

GIS research

A considerable amount of GIS research, like early IS research, is found in various conference proceedings and special publications, and thus may not be commonly available to many IS researchers. No less than five international GIS professional organizations actively sponsor annual conferences and all five of these jointly sponsor another major annual conference.

A large part of the body of knowledge in GIS has been self-reported case studies by various practitioners and consultants. Much of it focuses on physical and operational concerns of implementation. However, there have been some research works reported which considered valuation of GIS usage.

For example, Dickinson & Calkins (1988) proposed a general heuristic for calculating benefits of better decision-making due to contributions of a GIS. They propose a two-step process: (1) estimation of the effect of better decision-making (i.e., how much value would be added to the result of the decision-making process from better decision-making), and (2) estimation of the contribution of the GIS to better decision-making.

De Man (1988) points out the possibility that better information from a GIS can reduce risk for an organization. He discusses how GIS may be applied in decision-making for (1) *solution*-finding for well-structured problems[1], and (2) *problem*-finding for ill-structured problems. The present study focused on the first of these two classes of problems through presentation of a well-structured problem to experimental subjects engaged in *solution*-finding.

Some GIS research and practitioner-oriented reports are beginning to appear in more mainstream IS literature. For example, Lapalme, et al. (1992) have discussed GeoRoute, a GIS for transportation applications. Franklin (1992) provided a useful overview and glossary of GIS to the IS community. Churbuck (1992) introduced the potential uses of GIS in general business problems to IS practitioners.

Graphics / human-computer interaction research

Modern research in graphics display and information extraction dates as far back as 1927, when Washburne (1927) conducted a series of experiments with school children where he varied the type of information presentation -- tabular versus graphic versus textual -- and asked the subjects about the quantitative content of the information.

Many studies since then have focused on various aspects of how humans interact with graphical presentations of information. A significant number of these have had the objectives of contributing to the understanding of industrial controls design and of mechanical operator reactions to various types of information

[1]Doktor (1969) stated that task structure is a probabilistic characteristic . The greater the probability that there exists one best solution to a task, then the more structured the task is said to be. Ill-structured problems have low probabilities, and well-structured problems have high probabilities of existence of a single best answer.

presentation. For example, Wickens & Andre (1990) looked at how proximity of simultaneous displays of related information affected response times of an operator. This was similar to an earlier study by Keele (1970) where color and form of projected images were manipulated. The response time and response accuracy of experimental subjects were measured.

While useful as background for consideration of the various displays a GIS is capable of producing, these studies which focused on short-term physical response to graphical stimuli are not particularly helpful to the present study. This study was more concerned with how graphical representations of problem elements and spatial relationships of real objects and phenomena contribute to the understanding and solution of problems requiring more thought and reasoning.

Some studies have reported finding relationships of display format and task complexity. Zmud & Moffie (1983) found evidence of an interaction between report format and task complexity. Venkatesh & Verville (1992) conclude that it appears the use of a visual problem structuring aid promotes desired outcomes at the individual and group levels. GIS may provide such a visual problem structuring aid to the individual decision-maker in the present study.

An important area of graphics research which does lend assistance in grounding the current study in theory and prior research is Image Theory (IT), proposed by Bertin (1967, 1983). IT has been used as the basis of an earlier program of research at Indiana University, particularly the dissertations by Addo (1989), Davis (1986), Hoadley (1988), Joyner (1989), Lauer (1986), and Yoo (1985). In addition, other recent research by Tan & Benbasat (1990) has used IT as a basis for studying data extraction tasks and graphical representations.

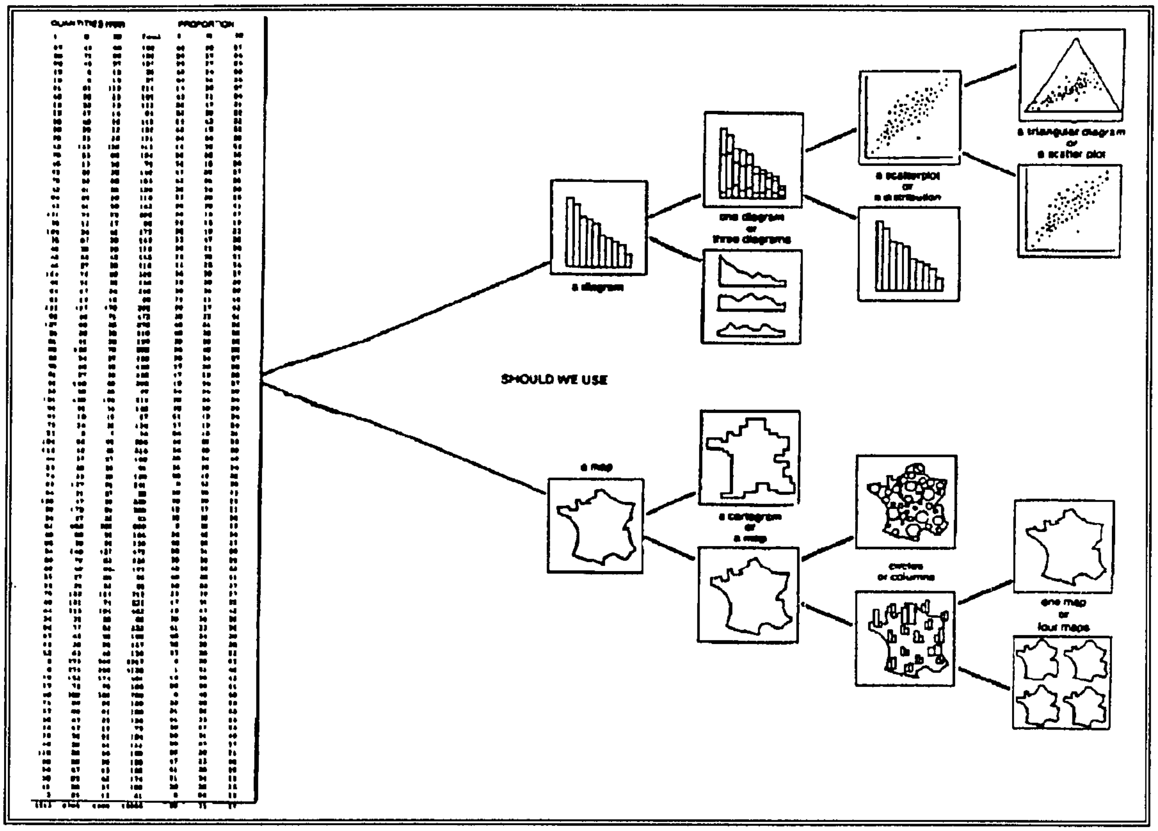
As an illustration of the many facets of representing tabular data graphically, Bertin (1983) constructed one hundred graphical representations from the same set of tabular data. He then categorized the various representations and showed two major groups of representation types (see Figure 2-1). The first group of representations is in the upper part of the figure, represented by various diagrams, scatter plots, etc. All of the effort at Indiana University thus far has been expended in this group.

However, an opportunity was identified for this study to explore part of the other half of representation types from IT. Note that the lower half of Figure 2-1 is concerned exclusively with maps and cartographic representations of the same set of data. This group of representations is presently untouched by the Indiana University research program, by IS research in general, and by the GIS community at large. The present study has built upon this map-based group of representations to more fully explore its implications for decision-making.

IT builds on efficiency as a basic premise. Bertin (1983) defines it as follows:

> EFFICIENCY is defined by the following proposition: If, in order to obtain a correct and complete answer to a given question, all other things being equal, one construction requires a shorter observation time than another construction, we can say that it is more efficient for this question.

FIGURE 2-1
TYPES OF GRAPHIC CONSTRUCTIONS
(AFTER BERTIN, 1983)



Bertin (1983) presented two additional facets of IT that have not been explored in previous works, which are concepts of images and figurations. An *image* is defined as a meaningful visual form, perceptible in the minimum instant of vision. Examples of images are single graphs and single maps, from which all the information necessary for a decision can be obtained from the one graphical display. Some concepts and multifaceted graphical illustrations, however, may be too complex to be represented by single images. Therefore, constructions of multiple images are required to fully represent them. Bertin (1983) terms these constructions of multiple images *figurations*. It is proposed in IT that such figurations are inherently less efficient than images for answering the majority of questions which can be asked about the data they represent.

The GIS practitioner literature is replete with references to the inherent inefficiencies of having a myriad of various paper maps and map-related tabular data which must be utilized to make decisions. The promise of GIS to reduce such inefficiencies is one of its major selling points. As one example, Weber (1990) describes how the Kentucky Department of Revenue literally had so many paper maps that it was physically impossible to assess taxation of its state coal reserves. GIS was employed to process the information and simplify the decision-making.

This study has built upon the concepts of images and figurations in its construction of the experimental task to be employed, and has measured the relative degree of efficiency related to such graphical constructions. The findings should contribute to an expansion of IT regarding the contribution of technologies which include computer graphics, such as GIS. A more detailed description of how the research design relates to IT is included later in Chapter 3.

Decision support systems research

One may ask the question whether a GIS is a decision support system (DSS). Sprague (1980) defined DSS as a computer-delivered decision aid system that contains data bases, model (or decision aid) bases, and interfaces and software that allow decision-makers or their assistants to use and alter the data and model bases in real time. GIS includes all these attributes, and thus is probably used as a DSS in most applications of the technology.

Discussions of DSS generally are concerned with the nature of the task and decision-making environment. Two major categories of DSS applications are generally recognized (Turban & Watkins, 1986). Turban & Watkins (1986), citing Goul, Shane, & Tonge (1984), describe systems which are used in problem finding. These may require an expert component to guide the user through the solution of relatively ill-structured problems, as described by Simon (1960). Reitman (1982), on the other hand, describes systems which are used primarily in decision-making and generally address well-structured problems, as described by Simon (1960).

Cats-Baril & Huber (1987) reported a laboratory experiment where they tested decision-making for an ill-structured problem. The independent variables which were manipulated were presence or absence of a decision-aiding heuristic, degree of interaction between the user and the delivery device, and whether the delivery device was a computer or pencil and paper. Dependent variables were quality of performance, productivity of ideas, user confidence in the quality of his/her performance, user satisfaction with the decision aid or support system, change in user attitude about the task, and change in user attitude about computers. This study has roughly adopted the Cats-Baril & Huber (1987) experimental model, except that the problem was well-structured.

Cognitive psychology research

Ives (1982) and Liberatore, Titus, & Dixon (1988) have pointed out the desirability of considering the characteristics of the individual as independent variables in any IS decision-making research study. Keen & Bronsema (1981) proposed that cognitive skills[2] are more appropriate for consideration when performances rather than preferences are being studied. The present study focused on two performance measures, and thus the examination of cognitive skills was appropriate.

Zmud & Moffie (1983) asserted that one specific cognitive skill that has consistently discriminated among decision performances in related IS research is field dependence[3]. They further maintain that people with lower field dependence tend to outperform those with higher field dependence in structured decision tasks and tend to make more effective use of transformed information (that is, aggregated values, graphical formats, etc.). Zmud & Moffie (1983) looked at field dependence as a factor in a study of the effect of report formats on decision accuracy and decision confidence. They found only minimal association of field dependence with accuracy and confidence, and that association was only viable for tasks of low complexity.

Liberatore, Titus, & Dixon (1988) state that field dependence has been used by many management and IS researchers as a

---

[2]Cognitive psychology refers to all processes by which sensory input is transformed, reduced, elaborated, stored, recovered, and used (Neisser, 1967). Abilities which utilize these processes are called cognitive skills. Decision-making and problem solving are considered "higher" cognitive skills (Reed, 1988).
[3]Field dependence relates to an individual's ability to separate an item from an organized field or to overcome an embedded context (Witkin, Lewis et al., 1954). Higher field dependence implies less of such an ability.

measure of cognitive style[4] and personality differences which may relate to decision-making performance, especially with regard to graphical displays. Liberatore, Titus, & Dixon (1988) proposed and used a framework to relate certain task characteristics to individual cognitive style. However, they considered only the tabular-versus-graphic aspect of studying graphical displays. The framework was two dimensional with three task types (financial, manpower, and scheduling) in one dimension, and type of display (graphic only, tabular only, and subject's choice of graphic or tabular) in the other. They reported no significant differences in performance related to field dependence, and claim that their findings extend those of prior comparative studies. However, they used only the single performance measure of accuracy and allowed subjects a fixed amount of viewing time.

Benbasat & Dexter (1985) considered field dependence of subjects as an independent variable and performance as a dependent variable. In their study performance was considered as both decision time and decision accuracy (that is, profit performance in the study). They reported no significant differences on decision time related to field dependence, and significant results for profit performance (i.e., accuracy) only for certain displays. They attribute poor performance on some display formats by field dependent subjects to a mismatch between information presentation and personality type. They conclude by suggesting that proponents of graphical information presentation must qualify

[4]Cognitive style has been defined by Doktor & Hamilton (1973) as a characteristic, self-consistent way of functioning that an individual exhibits across perceptual and intellectual activities.

their claims to task environments: (1) where there is a clearly defined rationale for the potential benefits of graphics usage, and; (2) where graphical reports are organized in a way to best support the task at hand. The present study meets both of these suggested qualifications.

Other studies which have looked at cognitive style, including field dependence, in decision-making include Doktor & Hamilton (1973) and Lusk & Kersnick (1979). Lusk & Kersnick (1979), in a study of the relationships of cognitive style and report format on task performance, used the field dependence measure to classify subjects as high (low field dependence) and low (high field dependence) analytics. Like Liberatore, Titus, & Dixon (1988), Lusk & Kersnick (1979) considered only solution accuracy as a performance measure, and used a fixed period of time for the subjects to work the experimental problem. They reported finding no significant support for their hypothesis that high analytics would achieve higher accuracy than low analytics, although there were some marginal indications in favor of it.

Swink (1991) included field dependence as an independent variable in a study of distribution network design by experienced decision-makers, but found no significant contribution of field dependence to task performance.

In a field dependent mode of perceiving, according to these authors, perception is strongly dominated by the overall organization of the surrounding field, and parts of the field are experienced as "fused." People with low field dependence, on the other hand, seem better able to experience different parts of a field as discrete from the organized background. Such characteristics related to field dependence were hypothesized to influence the performance of decision-makers using maps. The maps used in the study can be considered organized fields containing different parts which had to be differentiated in order to solve the task problem.

Another facet of cognitive style which may impact decision-making performance is an individual's internal motivation to engage in and enjoy thinking. This characteristic has been termed the need for cognition (NFC) by various researchers. Cohen, Stotland, & Wolfe (1955) described the NFC as a need to structure relevant situations in meaningful, integrated ways, and as a need to understand and make reasonable the experiential world. Cohen (1957) described findings which supported an hypothesis that individuals of high rather than low NFC are more likely to organize, elaborate on, and evaluate the information to which they are exposed.

Cacioppo & Petty (1982) developed an instrument to measure individual NFC. For the present study a shortened version of the Cacioppo & Petty (1982) NFC questionnaire instrument was administered to subject participants via questionnaire, and the scores were treated as an independent variable in the analysis. This shortened version is presently being studied and validated in at least one other study at Indiana University (Scudder, Herschel, and Crossland, 1992).

Prior research summary

This chapter reviewed significant prior research in the four areas related to this study: GIS research, graphics and human-computer interaction research, decision support systems research, and cognitive psychology research. The importance of each of these four areas to the current study was presented, as well as how each of them contribute to it. GIS, like its sister MIS, is very multidisciplinary in nature, and requires assimilation of representative research from all of these other areas before a proper study can be carried out.

The next chapter, Chapter 3, presents the research hypotheses and methodology employed in the study.

CHAPTER 3: RESEARCH HYPOTHESES AND METHODOLOGY

Hypotheses related to decision performance

Earlier studies in computer graphics research and image theory indicate that some information presentations are more efficient than others for use in decision-making. GIS technology goes a step further than this consideration, however. GIS does more than simply allow the color, style, and form of displays to be manipulated for greater efficiency of information extraction and interpretation. As was pointed out by Ives (1982), being able to electronically manipulate maps also enables new kinds of information processing and display which previously were either not possible, or were uneconomic to pursue. Thus it is proposed that there is economic benefit in using GIS technology for certain types of problems.

One of the most straightforward tests of the efficiency of a decision support system is to consider the time and accuracy with which solutions to problems are obtained. This same approach was adopted for this study.

A GIS may be considered to make a positive contribution to the decision-maker's task if it enables him or her to reach: (a) a more accurate solution, (b) a faster solution to a given problem, or (c) both of these. This study proposes that a GIS will present more efficient graphical displays (as defined in Image Theory) than conventional paper maps, it may be hypothesized that a user of GIS will benefit from the greater efficiencies predicted by Image Theory. Thus, the first two hypotheses in this study were:

> H1: Decision-makers using the GIS will solve a problem in less time than those using only paper maps for the same problem.
>
> H2: Decision-makers using the GIS will solve a problem with fewer errors than those using only paper maps for the same problem.

There are also efficiency questions related to problem complexity that this study addressed in an exploratory manner. One would intuitively expect decision time to increase and accuracy to decrease when the problem complexity is increased. And indeed, this was shown to be generally true by Addo (1989). Davis (1986), Hoadley (1988), Joyner (1989), Lauer (1989), and Yoo (1985). The present study was designed to test whether this relationship also holds true for a map-based decision task. Pursuant to this purpose, the following pair of hypotheses was posed:

> H3: As the problem complexity is increased, decision-makers using the GIS will exhibit less increase in solution time than those using only paper maps for the same type of problem.
>
> H4: As the problem complexity is increased, decision-makers using the GIS will exhibit less decline in solution accuracy than those using only paper maps for the same type of problem.

These hypotheses implied an expected interaction between problem complexity and GIS usage.

Hypotheses related to cognitive style factors

Ives (1982) and Liberatore et al. (1988) have pointed out the need to consider characteristics of individuals as factors in assessing the effects of use of computer graphics for problem solving. A cognitive characteristic commonly considered in such research is field dependence, which may be measured with a psychological test, the Group Embedded Figures Test (Witkin, Oltman et al., 1971). This test was administered to the experimental subjects in this study, and the degree of field dependence was compared to the performance of the decision-makers. Liberatore et al. (1988) have assimilated prior research on field dependence and related it to decision-making with computer graphics. This study views maps as complex fields which contain embedded information. Field dependent persons are comparatively passive receivers of information and tend not to structure or restructure a field, given situational demands, so they should be disrupted most when the set of graphical information becomes more complex, as is the case in the variable manipulations of the experiment in this study. They should exhibit a lower overall performance level than people who are less field dependent. Field dependence may be, therefore, a measure of aptitude for spatial problems. Thus the following hypotheses were proposed for the experiment:

H5: Individuals who are less field dependent will solve the experimental problem faster than individuals who are more field dependent.

H6: Individuals who are less field dependent will solve the experimental problem with fewer errors than individuals who are more field dependent.

Benbasat & Dexter (1985) and Lusk & Kersnick (1979) found no interaction between information presentation type and cognitive style (as measured by the GEFT), Liberatore et al. (1988) have suggested that this relationship may exist only in some specific, well-defined task environments. The experimental task in this study is one of these specific, well-defined task environments and the interaction should be testable.

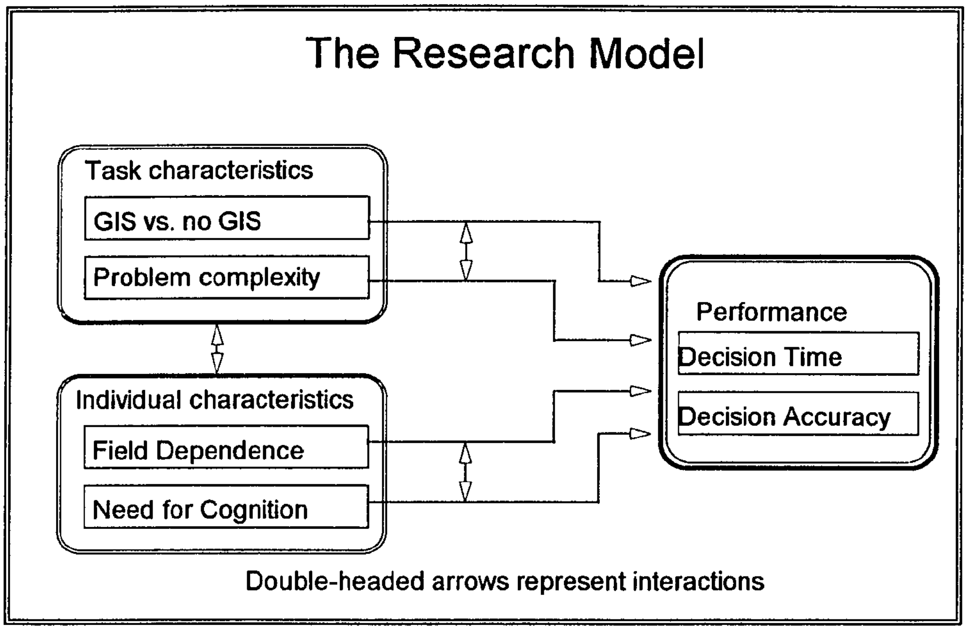
This study also investigated the relationship of one other cognitive style dimension to decision-making, the individual's need for cognition (NFC) as described by Cacioppo & Petty (1982) and used a shortened version of their NFC instrument. The NFC measures an individual's internal motivation to pursue and enjoy thinking activities. A person's NFC may affect decision task performance independently from his aptitude. This experiment hypothesized that higher NFC individuals would exhibit a higher level of performance on the task solution than their lower NFC counterparts. Thus the following hypotheses were stated for the study:

H7: Individuals who score higher on the need for cognition (NFC) scale will solve the experimental problem faster than individuals scoring lower on the NFC scale.

H8: Individuals who score higher on the NFC scale will solve the experimental problem with fewer errors than individuals scoring lower on the NFC scale.

Figure 3-1 illustrates the research model used for this study.

FIGURE 3-1
THE RESEARCH MODEL IN THIS STUDY



Variables and variable relationships

The study included four independent variables and two dependent variables.

Independent variables

The task characteristic independent variables were:

1. *Presence / absence of GIS technology.* This variable was manipulated on two levels. On one level the subjects had only paper maps and tabular data to determine a solution to the experimental problem. On the second level, subjects were additionally provided with a GIS which displayed graphical results of common data manipulations available in most GIS.

2. *Problem complexity.* The problem complexity variable was manipulated on two levels. The first level required subjects to rank order five facility sites using three spatial criteria. The second level required rank ordering of ten facility sites using seven spatial criteria.

The individual characteristic independent variables were:

3. *Field dependence.* Each subject's degree of field dependence was measured by administering the Group Embedded Figures Test (Witkin et al., 1971) prior to working the problem. It was scored using the published scoring guide for the test. Scoring was accomplished by simply counting the number of correct tracings of the embedded geometric figures on the test, with possible scores ranging from 0 to 18.

4. *Need for cognition.* Each subject's level of need for cognition (NFC) was assessed by administering the NFC questionnaire instrument (Cacioppo & Petty, 1982) prior to working the problem. The questionnaire consists of eighteen questions which are answered on a nine-point Likert scale. After reverse-coding nine of the questions, the NFC score is derived by simply summing the values of the answers for each of the eighteen questions. The gives a potential minimum score of 18 and a potential maximum score of 162.

Dependent variables

Two dependent variables were measured and analyzed in the study:

1. *Decision time.* The overall time to process the problem statement, arrive at a solution, and record the solution was measured unobtrusively by the computer used by each subject. Subjects were given an unlimited amount of time for the problem, and the start time and end time at two distinct points in the experiment were captured automatically into a database.

2. *Accuracy.* The solution determined by each subject was captured directly in a database. Because the problem is objective and has a predetermined correct solution, the computers automatically scored each subject's solution against the correct solution. The nature of the task required the subjects to rank order a series of alternative facility sites based on the various spatial criteria of the task. An error score was generated by summing over the total problem the absolute number of rank positions away from the correct position that each site was placed in a subject's ranking. Because two levels of problem complexity were being considered, the error score was converted to a percentage of total possible error for comparisons across cells of the research design matrix.

Controlled variables

Variables which could have an impact on the study and therefore were controlled were:

1. *Nature of task.* Each subject solved the same stated problem. Only problem complexity (number of items to rank and

number of criteria to consider) and the presence or absence of a decision aid (the GIS) were manipulated.

2. *Training.* All subjects received the same training for the main problem by working the same short training problem. The only difference for certain subjects was additional instructions on how to retrieve the necessary GIS displays from the computer.

3. *Experimental setting.* All subjects participated in the experiment in the same room, under the same physical conditions. Only subjects from a single experimental design cell were using the room at any given time. A computer-equipped classroom (Ballantine Hall, room 118) at Indiana University, with 31 IBM PS/2 Model 50 computers, was used during the entire study. All groups used the same software for answering questionnaires and recording solutions. The GIS software used for the study was MapInfo from MapInfo Corporation of Troy, New York.

4. *Solution scoring rule.* All subjects employed the same point-score solution rule to solve the problem. Each site was assigned specific point values based on each criterion. The total criteria points for each site were summed, and then sites were ranked based upon the point totals.

5. *Subject pool and assignment to design cells.* All subjects were recruited from various sections of the same introductory computer course (K201, The Computer in Business) in the School of Business at Indiana University. Subjects received course credit for participation in the study. Each subject was randomly assigned to one and only one of the experimental design cells.

Research methodology

The study involved manipulation of the availability of GIS technology and the problem complexity, measurement of individual field dependence by a standard timed test, and assessment of need for cognition by a pretask questionnaire.

The two dependent variables, decision time and accuracy, were measured jointly in accordance with the suggestions of Jarvenpaa (1989), Jarvenpaa & Dickson (1988), and Hoadley (1990). A questionnaire was administered to subjects at the end of the experiment.[1]

A four-cell, 2x2 factorial design was employed, with the unit of analysis being the individual decision-maker. The four experimental design cells for the treatments were:

1. No GIS, less complex problem
2. GIS, less complex problem
3. No GIS, more complex problem
4. GIS, more complex problem

For analyzing the individual cognitive style variables, each of these treatment cells was further subdivided once for analysis by categorizing each subject as high or low field dependence, then alternatively as high or low need for cognition. The final result is a pair of 2x2x2 factorial designs which were used for this analyses.

The two task-characteristic independent variables represented in this design are dichotomous nominal level variables. The two individual-characteristic independent variables (field dependence

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[1]While not a major part of the analysis for this study, the questionnaire was designed to assess the constructs of user confidence in the decision quality, user satisfaction with the solution process, and user attitude toward computers. These in turn have provided some additional richness to the study which will be a basis for further research.

and need for cognition) were measured as interval level variables and then systematically categorized to nominal level, based on interval ranges. The two dependent variables are both interval level. Data were analyzed using descriptive statistics, t-test comparisons, and univariate analysis of variance techniques as outlined in Chapter 4.

This research design follows Campbell & Stanley's (1963) Design 6, the posttest-only control group design, which is a true experimental design. It is represented in classical notation as:

$$\begin{array}{ccc} R & X & O_1 \\ R & & O_2 \end{array}$$

In this experiment the R's both represent the random assignment of subjects to independent design cells. The X is the experimental treatment, operationalized in two dimensions as the manipulated independent variables: addition of GIS technology and increase of problem complexity. The O_n's each represent a combination of the measured dependent variables: decision time and accuracy.

Underwood (1957), along with Campbell & Stanley (1963), pointed out that blocking on subject variables provides an increase in the power of the significance test which is very similar to that provided by a pretest. In the present study this blocking is provided by the measured independent variables of individual cognitive style: field dependence and need for cognition.

Results of the pilot study

A pilot study for this project was completed in late September, 1991. The experimental design was tested in all four treatment cells, with a total of 33 subjects distributed among the four cells in a 7-7-9-10 fashion. The main purposes of the pilot study were to test the numerous software programs which were developed for this study, to test experimental procedures, and to estimate expected effect size and variance.

The data from the pilot study were sufficiently satisfactory to begin the main study with no significant changes in the research design or experimental procedures. The pilot data were judged reliable and adequate to be pooled with the main study for the final analysis, resulting in a final sample size of 142.

Experimental procedure

Experimental subjects were recruited, as described above, and confirmed by phone to attend their assigned session. Each subject was mailed a confirmation of the appointment, a short demographic questionnaire (see Appendix 1), and a set of five pressure-sensitive labels which showed his/her appointment date and time, session number, and subject identification number. These labels were used by the subjects to mark each of the various items collected during the experiment.

Thirty-two subjects were recruited for a pilot study, and 110 subjects were recruited for the main study. Each subject was randomly assigned to one and only one of the four experimental design cells. Random assignment was accomplished using a program developed by the researcher using dBASE IV. Each subject's contact information (e-mail address, phone, address, etc.) and time-period availability was loaded into a dBASE IV database. The dBASE computer program then was used to assign subjects to groups by randomly assigning them to one of the several time periods for which they had indicated their availability.

At the appointed time subjects checked in to the experimental site and loaded the experiment software on their respective machines, using an automated installation routine developed by the researcher. After successful loading of the required software, subjects placed blank floppy disks in their computers to record the answers and elapsed time.

The group received brief introductory comments, followed by administration of the need for cognition questionnaire (Appendix 2) on each subject's computer workstation. Next the Group Embedded Figures Test was administered to each participant.

The need for cognition questionnaire was administered using an interactive computer program developed by the researcher for this study. The program was written as a run-time application in dBASE IV. Each subject was initially asked for his/her subject identification number, which was printed on the labels previously mailed to each subject. This number was immediately recorded on the floppy disk in a database file. Each subject then answered the NFC questionnaire, and the answers were recorded on the floppy disk as a dBASE file. This approach virtually eliminated data transcription prior to analysis and served to ensure data accuracy and timely analysis.

A short practice task (Appendix 3) was then given to the subjects to familiarize them with the methodology to be used, the organization of the printed materials, the nature of the task, and how to manipulate the computer to record the solution to the problem. Subjects in the two design cells with GIS technology were additionally given instructions on how to retrieve and manipulate the displays required to solve the problem.

The subjects were then given the main problem task. For each of the four experimental groups, the subjects were offered a cash prize of $15 for first, $10 for second, and $5 for third place, based first on decision accuracy, then on elapsed time as a tie breaker. The cash prizes were paid immediately upon the completion of each group's experiment.

Before working on the main problem, the subjects were first shown a short (5-minute) videotape of a recent news feature which detailed the subject of the main problem, a new type of electric power generation technology. This was intended to enhance a sense of realism for the problem. They then received the main problem materials and were asked to solve the problem. The main problem statement, supporting maps, and scoring sheet are included in Appendix 4 (less complex problem) and Appendix 5 (more complex problem).

Each subject was asked to select a certain menu choice from the computer just before removing the main problem from the envelope. This menu choice served one or two purposes. First, it recorded the subject's start time in the database file on the floppy disk. Second, for those subjects who had a GIS, it initiated the drawing of the first GIS map on the computer screen while the subject was reading the problem.

Each subject worked the problem individually using only the written materials provided and, in the case of the GIS groups, the GIS displays. Subjects who were provided the GIS were encouraged to use the GIS displays as their primary source of information but they were permitted to use any of the written materials, which were identical to those used by the non-GIS group of the same problem complexity. The display screens used by the GIS group are illustrated in Appendix 6 (less complex problem) and Appendix 7 (more complex problem).

After scoring each of the sites by using the written materials and/or GIS displays, the subjects transferred their scores for each site on each criterion from their respective scoring sheets into the computer as prompted by a series of input screens. This was followed by input of the final ranking of each site as determined by the subject. The final rank was the only input that was scored, but the individual site scores were captured and retained for later analysis. Once the subject had indicated completion of entry of the final scores and rankings, the computer automatically recorded the ending time in the database file on the subject's floppy disk.

After each subject entered the final ranking of each site, he/she was automatically administered a post-task questionnaire on the computer. This questionnaire was one of two developed for this study. Subjects who did not use the GIS answered 32 questions (Appendix 8) designed to evaluate the four constructs of user solution confidence (questions 1-8), level of motivation (questions 9-16), user process satisfaction (questions 17-24), and subject attitude toward computers in general (questions 39-46). Subjects who used the GIS displays answered 46 questions (Appendix 9). This questionnaire included all of the 32 questions of the non-GIS group, but added two additional constructs related to the computer graphics displays: ease of use (questions 25-32) and level of use relative to the paper maps (questions 33-38).

Following completion of the questionnaire by all participants, each subject instructed the computer, through a menu choice requiring a password, to display the final error score and elapsed time. A password was used because some of the post-task questions addressed the subjects' confidence in their answers and sense of achievement relative to other participants; thus, the final score of any subject was not revealed until all had finished. Although this created some wait time for an early finisher, it did not affect a subject's measured outcomes since the study and measures for that subject were all complete at that point. Subjects who finished the task early were able to read or visit quietly with other subjects who had completed the task. These behaviors did not interfere with others still working on the problem, so this was judged not to be a problem.

Upon completion of the problem by all subjects, the group was polled for the lowest error score, followed by a poll of shortest elapsed time if there was a tie on the error score. Cash prizes were then awarded and the group thanked and dismissed. Following dismissal all materials for each subject, including floppy disks with each subject's data on them, were collected and analysis begun.

All instructions to the group throughout the study followed a written script (Appendices 10 and 11).

Summary of hypotheses and methodology

Eight hypotheses were proposed in this study. These hypotheses represented four areas of inquiry: (1) effect on task performance of use versus nonuse of GIS; (2) effect on task performance of the interaction of GIS usage with task complexity; (3) relationship of individual field dependence to task performance; and (4) relationship of individual need for cognition to task performance.

A laboratory experiment was designed to test the eight hypotheses. It consisted of a 2 x 2 matrix of experimental treatments (GIS use or nonuse, and two levels of problem complexity) following Campbell & Stanley's (1963) Design 6, the posttest-only control group design. The research design was first tested with a pilot study and was found to be feasible. Two measures of individual cognitive style, field dependence and need for cognition, were assessed pre-task by test and questionnaire, respectively. Each of these independent variables was compared with two dependent variables representing individual performance, solution time and accuracy.

Volunteer experimental subjects were recruited from an undergraduate business computing course, yielding a total experimental sample of 142 subjects. The results of the data collection were subjected to the analyses detailed in the next chapter.

CHAPTER 4: RESULTS

Overview

The experiment in this study was designed to measure the relationships of decision time and accuracy to four independent variables. The first two of the independent variables, presence or absence of GIS technology and problem complexity, are task characteristics and were manipulated for the experiment. These two variables encompassed the main thesis of this investigation, and the analysis techniques employed follow common hypothesis testing norms for the experimental design.

The remaining two independent variables, field dependence and need for cognition, are individual decision-maker characteristics and were measured by pre-task test and questionnaire instruments. Investigation of these variables was considered exploratory in this study, and the analysis techniques employed reflect this exploratory approach.

Statistical model

The research design follows Campbell & Stanley's (1963) Design 6, the posttest-only control group design, with two dimensions of manipulated factors and two dimensions of subject variables (Underwood, 1957). Thus, an analysis of variance statistical model, as recommended by Campbell & Stanley (1963) for such designs, was employed as the primary model for comparing the means of the dependent variables. In addition, independent sample t-tests were used for comparisons of between-cells means of the dependent variables on the two task characteristic independent variables.

Descriptive statistics

A total of 142 subjects completed the experiment, including 88 men and 54 women. The subjects were randomly assigned to one of the four experimental treatment groups. Thirty-two subjects participated in the pilot phase of the experiment, and 110 participated in the final phase. Results from the pilot phase and the final phase were pooled for the final analysis. Due to scheduling and subject availability constraints, there was some variance in the final number of subjects per treatment group, as shown in Table 4-1.

TABLE 4-1
DISTRIBUTION OF SUBJECT'S PERSONAL CHARACTERISTICS AMONG EXPERIMENTAL GROUPS

				Computer			Maps/ Cartog.		Age			
	No. in Group	No. Male	No. Female	Prev. exper.	Used in a job	Problem-solving	Used in a job	Problem-solving	min	max	avg	std dev
Simple, No GIS	37	18	19	29	16	5	2	2	18	40	19.9	3.42
Simple, GIS	38	28	10	31	15	5	5	6	18	36	20.2	3.32
Complex, No GIS	33	20	13	25	10	1	2	0	18	23	19.2	0.88
Complex, GIS	34	22	12	30	16	1	3	2	18	30	19.9	2.20
Totals	142	88	54	115	57	12	12	10				

Table 4-1 is a tabulation of the various demographic characteristics of subjects. These were collected using a questionnaire (Appendix 1) to establish that there were no significant assymetrical distributions of these characteristics which might affect the analysis. None were identified.

The average age of the subjects was 19.8 years. Eighty-one percent of subjects reported some previous computer experience. Forty percent said they had used computers in some capacity as an employee. Only eight percent claimed previous experience in using computers in problem-solving. Eight percent said they had used maps as part of an employment experience. Only seven percent said they had used maps for problem-solving. Sixty-two percent were men, and thirty-eight percent were women.

For the two performance measures of solution time and accuracy, the scores in the four experimental treatment groups are listed in Table 4-2 and Table 4-3, respectively. A summary of the scores for the two individual characteristic variables, which were measured by pretask instruments, is listed in Table 4-4. Correlations of the six variables are shown in Table 4-5. There were no significant correlations of any of the variables, so there were no apparent problems for the analysis which might be attributed to multicollinearity.

TABLE 4-2
MEAN SOLUTION TIMES IN MINUTES

SOLUTION TIMES / STANDARD DEV	LOW COMPLEXITY	HIGH COMPLEXITY	ROW AVERAGES
NO GIS	14.6 / 3.08	35.6 / 10.00	25.1 / 6.54
GIS	13.1 / 3.08	30.2 / 8.76	21.7 / 5.92
COLUMN AVERAGES	13.6 / 3.08	32.9 / 9.38	

TABLE 4-3
MEAN PERCENT ERROR

PERCENT ERROR / STANDARD DEV	LOW COMPLEXITY	HIGH COMPLEXITY	ROW AVERAGES
NO GIS	8.1 / 18.26	8.2 / 7.55	8.2 / 12.91
GIS	0.0 / 0.00	2.8 / 3.85	1.4 / 1.93
COLUMN AVERAGES	4.1 / 9.13	5.5 / 5.7	

TABLE 4-4
INDIVIDUAL COGNITIVE STYLE SCORES SUMMARY

INDIVIDUAL FACTOR	N	MEAN	STD DEV
Field dependence	142	12.4	4.40
Need for cognition	142	105.9	20.65

Table 4-5
CORRELATION MATRIX OF VARIABLES

	Time	PE	FD	NFC
Time	1.00			
Percent Error (PE)	.15	1.00		
Field dependence (FD)	-.07	-.09	1.00	
Need for cognition (NFC)	-.08	.05	.12	1.00

no correlations were significant at p<.05 level

Analysis for GIS usage and problem complexity

The first phase of analysis focused on determining the relationships of the treatment variables, GIS usage and problem complexity, to the two dependent variables, solution time and accuracy[1]. Analysis of variance was the primary investigative tool. Because cell sizes were not equal in the ANOVA, additional confirmatory analyses were done using an independent sample t-test comparison of means, which is not sensitive to differences in cell sizes.

Analysis of variance

For the research designed employed in this study, Campbell & Stanley (1963) recommended analysis of variance (ANOVA) as one of the most powerful analysis techniques. Therefore, hypotheses H1

[1]Percent error was used for comparisons across different-complexity problems. Because there can be problems associated with using percentages or other ratios in ANOVA (Sokal & Rohlf, 1969) a separate analysis was performed using an arcsin transform of the percent error. Aside from very slightly increasing the significance of the results, the analyses were identical. Therefore, the ANOVA results obtained from the percentage data are reliable.

and H2 were initially tested using ANOVA. From Chapter 3, the hypotheses were:

> H1: Decision-makers using the GIS will solve a problem in less time than those using only paper maps for the same problem.
>
> H2: Decision-makers using the GIS will solve a problem with fewer errors than those using only paper maps for the same problem.

ANOVA was appropriate for this study for a second reason. It was also hypothesized in this study in Hypotheses H3 and H4 that there would be an interaction between the use or nonuse of a GIS and problem complexity:

> H3: As the problem complexity is increased, decision-makers using the GIS will exhibit less of an increase in solution time than those using only paper maps for the same type of problem.
>
> H4: As the problem complexity is increased, decision-makers using the GIS will exhibit less of a decline in solution accuracy than those using only paper maps for the same type of problem.

Therefore, to make an even more powerful comparison (Huck, Cormier, & Bounds, 1974) of the sample means related to Hypotheses H1 and H2, as well as to make an analysis of the hypothesized interaction, a full-factorial two-way ANOVA was used to examine the data from the experiment. The assumptions necessary for the proper application of ANOVA in the case of a single independent variable are that the groups must be random samples from normal populations with the same variance (SPSS, 1988a). Albright (1987) states that when the sample size of every group exceeds 30, as it does for each of the experimental design cells, then the sampling distribution may be assumed to be approximately normal. Also, because all subjects were drawn from the same undergraduate course and randomly assigned to the treatment groups, there is no *a priori* reason to suspect any systematic differences in subjects among groups. The subject characteristics data (Table 4-1) confirmed this. Therefore, the assumptions for ANOVA are assumed to be met in this study, particularly in consideration of three points: (1) the relatively large sample size of 142, (2) the reasonably high statistical power level, and (3) the fact the ANOVA is robust to violations of these assumptions (Lindman, 1990).

In addition to these sample distribution assumptions, ANOVA also assumes the sample sizes within every group to be equal, creating a so-called balanced design (Albright, 1987). ANOVA examines F ratios which are derived from simple sums of squares across the cells of the design. In cases where the number of samples in every cell is not equal, variations in the F ratios may be induced which are simply due to these differences in sample size rather than to differences in between-cells means.

Because the four experimental groups analyzed by the ANOVA in this study had slightly different cell sizes, there was a possibility that some of the differences observed in the ANOVA were due to unequal cell sizes. According to Lindman (1990) this may be tested by using the hierarchical method in SPSS. This method allows the order of entry of the variables in the ANOVA to be specified and keeps the variables orthogonal. After completing the analysis once, order of entry is reversed and the results checked for any changes from the previous analysis. In this study the two analyses produced almost identical results, so unequal cell sizes was judged not to be a significant factor in the analysis.

Multivariate analysis of variance (MANOVA) was also considered for the analysis. The assumptions for using MANOVA are the same as for using univariate ANOVA, but MANOVA additionally assumes that the samples are from a multivariate normal population. The data in this study could be shown to reasonably meet these assumptions. However, in this study it was desirable to consider the unique relationships of each independent variable to each dependent variable. MANOVA only tests the relationship of each independent variable to a multivariate combination of all dependent variables. In order to estimate effects on individual dependent variables when using MANOVA, one must use univariate ANOVA tests in addition to the MANOVA results. Because in this study these univariate relationships were of primary interest, univariate ANOVA was employed rather than MANOVA for the analysis of both solution time and accuracy against the two treatment variables of GIS availability (or not) and problem complexity.

Table 4-6 shows the results of the ANOVA for solution time, while Table 4-7 shows the results of the ANOVA for percent error.

TABLE 4-6
RESULTS OF ANOVA FOR SOLUTION TIME (minutes)

SOURCE	SS	df	MS	F	p
Problem complexity (A)	12828.1	1	12828.1	275.54	.000
GIS availability (B)	392.1	1	392.1	8.42	.004
A X B	136.0	1	136.0	2.92	.090
Residual	6424.7	138	46.6		
Total	19780.9	141			

TABLE 4-7
RESULTS OF ANOVA FOR PERCENT ERROR

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	79.0	1	79.0	0.76	.384
GIS availability (B)	1659.5	1	1659.5	16.00	.000
A X B	63.8	1	63.8	0.62	.434
Residual	14312.4	138	103.7		
Total	16114.7	141			

Because there are significant main effects in the ANOVA on both solution time and percent error for the availability (or not) of GIS, Hypotheses H1 and H2 are supported. However, since there was not a significant interaction of GIS availability and problem complexity at the desired $p<.05$ level of significance for either dependent variable, neither H3 nor H4 is supported. Assuming a large effect size for solution time (because of the small residual) and a medium effect for percent error, and using the tables from Cohen

(1988), the ANOVA tests have statistical power of approximately 0.99 and 0.70, respectively.

Independent sample t-test comparisons of means

Hypotheses H1 and H2 were initially tested using univariate analysis of variance as outlined in the previous section. However, the ANOVA used slightly unequal cell sizes, which could induce some error. As confirmatory (albeit less powerful) analyses of the main effects, simple one-tailed, independent sample t-test comparisons of mean solution times and mean percent error were examined for same-complexity problems.

The only assumption necessary for the t-test is that the samples are normally distributed with equal variances. The t-test makes no assumptions about equal sample sizes. According to Albright (1987), when the sample sizes exceed 30, as they do in this case, then the sampling distribution may be assumed to be approximately normal. The statistic used to test the hypothesis that the two population variances are equal is the F-value, which is the ratio of the larger sample variance to the smaller. If the observed significance of the F-value is small (i.e., $p<.05$) then the hypothesis that the population variances are equal is rejected, and a separate variance estimate t-test is appropriate. If the observed significance of the F-value is large (i.e., $p>.05$), which it is in both cases below, then the hypothesis that the population variances are equal is not rejected, and a pooled variance estimate t-test, as used in Tables 4-8 and 4-9, is appropriate (SPSS, 1988b).

Table 4-8 and Table 4-9 show the results of the one-tailed, independent sample t-tests for Hypothesis H1 for low complexity and high complexity problems, respectively.

TABLE 4-8
INDEPENDENT SAMPLES T-TEST OF SOLUTION TIMES (minutes)
FOR GIS VS. NO GIS ON LOW COMPLEXITY PROBLEM

				Pooled Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS	38	13.1	3.076	1.00	1.000	2.08	73	.021
no GIS	37	14.6	3.075					

TABLE 4-9
INDEPENDENT SAMPLES T-TEST OF SOLUTION TIMES (minutes)
FOR GIS VS. NO GIS ON HIGH COMPLEXITY PROBLEM

				Pooled Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS	34	30.2	8.76	1.31	.450	2.35	65	.011
no GIS	33	35.6	10.00					

At a significance level of $p<.05$, both of the preceding tests are significant. There are, therefore, significant differences in mean solution time for both complexity-level groups, and Hypothesis H1 is supported. Assuming a medium effect size and using the tables from Cohen (1988), the test for the low complexity task has a statistical power of about 0.96, while that for the high complexity task has a statistical power of about 0.95.

Table 4-10 and Table 4-11 show the results of the one-tailed, independent sample t-tests for Hypothesis H2 for low complexity and high complexity problems, respectively.

TABLE 4-10
INDEPENDENT SAMPLES T-TEST OF PERCENT ERROR FOR GIS VS. NO GIS ON LOW COMPLEXITY PROBLEM

				Separate Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS	38	0.0	0.00	*	*	2.70	36	.005
no GIS	37	8.1	18.26					

* *F-value is undefined due to zero variance in the GIS case*

TABLE 4-11
INDEPENDENT SAMPLES T-TEST OF PERCENT ERROR FOR GIS VS. NO GIS ON HIGH COMPLEXITY PROBLEM

				Separate Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS	34	2.8	3.85	3.84	.000	3.69	47.28	.001
no GIS	33	8.2	7.55					

At a significance level of $p<.05$, both of the preceding tests are significant. There are, therefore, significant differences in mean percent error for both complexity-level groups, and Hypothesis H2 is supported. Assuming a medium effect size and using the tables from Cohen (1988), the test for the low complexity task has a statistical power of about 0.96, while that for the high complexity task has a statistical power of about 0.95.

Because the observed significance of the F-value is small (i.e., $p<.05$) in at least one of these cases (the F-value for one case is undefined due to zero variance in the sample), the hypothesis that the population variances are equal is rejected, and the separate variance estimate t-test, as used in Tables 4-10 and 4-11, is appropriate (SPSS, 1988b).

Analysis of field dependence

Two hypotheses in this study were concerned with individuals' field dependence as it relates to individual performance on the task:

> H5: Individuals who are less field dependent will solve the experimental problem faster than individuals who are more field dependent.

> H6: Individuals who are less field dependent will solve the experimental problem with a higher accuracy than individuals who are more field dependent.

Scores on the group embedded figures test of the 142 subjects in this study ranged from 0 to 18, with a median of 14.0, a mean of 12.35, and standard deviation of 4.40 (Table 4-4). Scores closer to 0 imply greater field dependence, while moving closer to a score of 18 implies less field dependence.

Analysis of variance

Because the subjects were divided into four treatment groups, it was desirable to maintain this categorization in the analysis of field dependence. Also, since the concept of high and low scores on the GEFT implied additional categorization for field dependence, a three-way ANOVA was judged appropriate to analyze both dependent variables against field dependence. The first phase of this analysis split the subjects into two categories at the sample mean of their GEFT scores. The resulting categories were analyzed using a 2 X 2 X 2 full-factorial ANOVA, the results of which are shown in Table 4-12 and Table 4-13.

TABLE 4-12
RESULTS OF FIELD DEPENDENCE (MEAN SPLIT) ANOVA FOR SOLUTION TIME (minutes)

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	12828.1	1	12828.1	277.04	.000
GIS availability (B)	392.1	1	392.1	8.47	.004
Field dependence (C)	140.9	1	140.9	3.04	.083
A X B	115.2	1	115.2	2.49	.117
A X C	80.7	1	80.7	1.74	.189
B X C	4.0	1	4.0	0.09	.770
A X B X C	2.3	1	2.3	0.05	.826
Residual	6204.67	134	46.3		
Total	19780.9	141			

TABLE 4-13
RESULTS OF FIELD DEPENDENCE (MEAN SPLIT)
ANOVA FOR PERCENT ERROR

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	79.0	1	79.0	0.75	.389
GIS availability (B)	1659.5	1	1659.5	15.68	.000
Field dependence (C)	56.4	1	56.4	0.53	.467
A X B	69.5	1	69.5	0.66	.419
A X C	45.4	1	45.4	0.43	.514
B X C	14.9	1	14.9	0.14	.708
A X B X C	6.7	1	6.7	0.06	.801
Residual	14184.3	134	105.9		
Total	16114.7	141			

The results of this phase of analysis of field dependence show no significant effects at $p<.05$ on either dependent variable. Therefore, neither Hypothesis H5 nor H6 is supported with this particular analysis. In addition, there were no significant interactions of field dependence with problem complexity nor with GIS availability.

After these initial results, exploratory work was undertaken to examine other possible splits of the subjects on the field dependence scores, including 1/2 and one standard deviation above and below the sample mean. It became apparent that there were some interesting breaks in level of performance as one moved away from the sample mean for a split point. One of the more promising of these was at a point 1/2 standard deviation below the sample mean. This meant categorizing scores of 10 and below as high field dependence (44 subjects) and treating the remainder as the other category (98 subjects). When this categorization scheme was used for field dependence, the results in Table 4-14 and Table 4-15 were obtained.

TABLE 4-14
RESULTS OF FIELD DEPENDENCE
(SPLIT AT 1/2 STD DEV BELOW MEAN)
ANOVA FOR SOLUTION TIME (minutes)

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	12828.1	1	12828.0	299.00	.000
GIS availability (B)	392.1	1	392.1	9.14	.003
Field dependence (C)	387.5	1	387.5	9.03	.003
A X B	105.4	1	105.4	2.50	.119
A X C	242.9	1	242.9	5.66	.019
B X C	14.1	1	14.1	0.33	.567
A X B X C	18.8	1	18.8	0.44	.510
Residual	5749.0	134	42.9		
Total	19780.9	141			

TABLE 4-15
RESULTS OF FIELD DEPENDENCE
(SPLIT AT 1/2 STD DEV BELOW MEAN)
ANOVA FOR PERCENT ERROR

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	79.0	1	79.0	0.74	.390
GIS availability (B)	1659.5	1	1659.5	15.64	.000
Field dependence (C)	64.4	1	64.4	0.61	.437
A X B	63.3	1	63.3	0.60	.441
A X C	20.4	1	20.4	0.19	.662
B X C	5.8	1	5.8	0.54	.816
A X B X C	1.8	1	1.8	0.02	.897
Residual	14223.3	134	106.1		
Total	16114.7	141			

The results of this second phase of analysis of field dependence show that there is a significant main effect of field dependence on solution time, as well as a significant interaction of field dependence with problem complexity. In terms of the interaction, field dependent people on average worked about 23.5 minutes longer on the more complex problem than on the simpler problem, while less field dependent people worked only 17.5 minutes longer. This result is from independent groups, not repeated measures.

These results support Hypothesis H5. No significant effects of field dependence on accuracy were found in this phase, so Hypothesis H6 is not supported.

Because this second phase of analysis of field dependence followed a nonstandard method of splitting the data into categories, a more conventional approach was desired in order to gain more validity. The second phase indicated that the significant differences lay toward the extremes of the data set. One method of splitting samples into analysis groups to emphasize extremes is to sort the sample, divide it into thirds, then delete the middle third. The remaining high and low thirds are retained for the analysis. This was done for a third and final phase of analysis of field dependence, and the results are shown in Table 4-16 and Table 4-17.

TABLE 4-16
RESULTS OF FIELD DEPENDENCE
(HIGH AND LOW THIRDS)
ANOVA FOR SOLUTION TIME (minutes)

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	7967.3	1	7967.3	158.65	.000
GIS availability (B)	253.3	1	253.3	5.04	.027
Field dependence (C)	347.6	1	347.6	6.92	.010
A X B	16.4	1	16.4	0.33	.570
A X C	364.3	1	242.9	7.26	.009
B X C	8.7	1	8.7	0.17	.677
A X B X C	0.5	1	0.5	0.00	.975
Residual	4318.9	86	50.2		
Total	13353.7	93			

TABLE 4-17
RESULTS OF FIELD DEPENDENCE
(HIGH AND LOW THIRDS)
ANOVA FOR PERCENT ERROR

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	1.6	1	1.6	0.01	.913
GIS availability (B)	1182.5	1	1182.5	9.06	.003
Field dependence (C)	21.1	1	21.1	0.16	.689
A X B	84.4	1	84.4	0.65	.423
A X C	146.1	1	146.1	1.12	.293
B X C	5.9	1	5.9	0.05	.832
A X B X C	23.7	1	23.7	0.18	.671
Residual	11222.1	86	130.5		
Total	12643.5	93			

This third phase of analysis of field dependence affirms, with a more conventional split of the data, the same results previously obtained with the less conventional split in the second phase. Once again, Hypothesis H5 is supported, whereas Hypothesis H6 is not supported. Also, there is once again evidence for a significant interaction between field dependence and problem complexity with respect to solution time, as was demonstrated in the second phase of analysis of field dependence.

Assuming a medium effect size and using the tables from Cohen (1988), the ANOVA for field dependence has a statistical power of about 0.69.

Independent sample t-test comparisons of means

ANOVA assumes equal sample sizes in each of the analysis cells. The ANOVA described in the previous section violates this assumption. Subjects were not tested for field dependence prior to their assignment to groups. Therefore, field dependence was not used to assign subjects to cells. This resulted in imbalances in the cell sample sizes which were used in the ANOVA.

The t-test requires no assumptions regarding sample sizes. As an additional test for significant differences due to field dependence, a series of independent sample t-tests were constructed, one for each of the design cells. The results of these t-tests are shown in Tables 4-18 through 4-21 .

TABLE 4-18
INDEPENDENT SAMPLES T-TEST OF SOLUTION TIME FOR HIGH VS. LOWER FIELD DEPENDENCE ON LOW COMPLEXITY PROBLEM

				Pooled Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS lower FD	11	13.9	2.14					
				2.47	.136	1.02	36	.157
GIS high FD	27	12.8	3.37					
no GIS lower FD	15	15.3	2.81					
				1.32	.603	1.12	35	.135
no GIS high FD	22	14.1	3.22					

TABLE 4-19
INDEPENDENT SAMPLES T-TEST OF SOLUTION TIME FOR HIGH VS. LOWER FIELD DEPENDENCE ON HIGH COMPLEXITY PROBLEM

Group	N	Mean	Std Dev	F	p	t	df	1-tail p
				Pooled Variance Estimate				
GIS lower FD	26	28.2	2.14					
				1.53	.587	2.63	32	.007
GIS high FD	8	36.8	3.37					
				Separate Variance Estimate				
no GIS lower FD	23	34.0	7.49					
				3.50	.016	1.15	11.31	.137
no GIS high FD	10	39.4	14.01					

TABLE 4-20
INDEPENDENT SAMPLES T-TEST OF PERCENT ERROR FOR HIGH VS. LOWER FIELD DEPENDENCE ON LOW COMPLEXITY PROBLEM

				Pooled Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS lower FD	27	0.0	0.00	*	*	.00	36	1.000
GIS high FD	11	0.0	0.00					
no GIS lower FD	22	7.6	19.73	1.43	.497	.12	35	.417
no GIS high FD	15	8.9	16.50					

* *F-value is undefined due to zero variance in the GIS case*

TABLE 4-21
INDEPENDENT SAMPLES T-TEST OF PERCENT ERROR FOR HIGH VS. LOWER FIELD DEPENDENCE ON HIGH COMPLEXITY PROBLEM

				Pooled Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS lower FD	26	2.3	3.74					
				1.12	.759	1.43	32	.081
GIS high FD	8	4.5	3.96					
no GIS lower FD	23	7.5	6.86					
				1.76	.269	.88	31	.193
no GIS high FD	10	10.0	9.09					

These t-tests support the results of the ANOVA for field dependence, albeit in a more limited fashion than was desired. There was a significant (p<.01) difference in solution time between high field dependents and lower field dependents on the high complexity problem when GIS was used. Weaker significance (p<.10) was found for percent error in this same experimental cell. There were no other significant differences observed in the t-tests. However, this result helps to lessen concerns about unequal sample sizes used in the ANOVA.

Analysis of need for cognition

Need for cognition (NFC) scores for the 142 subjects in this study ranged from a minimum of 42 to a maximum of 156, with a median of 107.5, a mean of 105.9, and standard deviation of 20.65 (Table 4-4). Higher scores indicate a higher need for cognition.

Analysis of need for cognition was designed to examine hypotheses H7 and H8:

> H7: Individuals who score higher on the need for cognition (NFC) scale will solve the experimental problem faster than individuals scoring lower on the NFC scale.
>
> H8: Individuals who score higher on the NFC scale will solve the experimental problem with a higher accuracy than individuals scoring lower on the NFC scale.

Analysis of variance

Analysis of the NFC followed the same three-phase pattern as that used for field dependence. First, the subjects were split into two groups at the sample mean of the NFC scores. As with the analysis of field dependence, it was judged necessary to compare high and low NFC scores within each experimental treatment group in order to test for interactions. Therefore, a 2 X 2 X 2 full-factorial ANOVA was used to analyze NFC against the two dependent variables. The results of this first phase of analysis are shown in Table 4-22 and Table 4-23.

TABLE 4-22
RESULTS OF NEED FOR COGNITION (MEAN SPLIT)
ANOVA FOR SOLUTION TIME (minutes)

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	12828.1	1	12828.1	280.29	.000
GIS availability (B)	392.1	1	392.1	8.57	.004
Need for cognition (C)	37.6	1	37.6	0.82	.366
A X B	164.1	1	164.1	3.59	.060
A X C	223.5	1	223.5	4.88	.029
B X C	10.6	1	10.6	0.23	.632
A X B X C	18.0	1	18.0	0.39	.532
Residual	6133.0	134	45.8		
Total	19780.9	141			

TABLE 4-23
RESULTS OF NEED FOR COGNITION (MEAN SPLIT)
ANOVA FOR PERCENT ERROR

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	79.0	1	79.0	0.74	.390
GIS availability (B)	1659.5	1	1659.5	15.64	.000
Need for cognition (C)	4.7	1	4.7	0.05	.833
A X B	68.5	1	68.5	0.65	.423
A X C	0.3	1	0.3	0.00	.955
B X C	33.3	1	33.3	0.31	.576
A X B X C	57.7	1	57.7	0.54	.462
Residual	14216.9	134	106.1		
Total	16114.7	141			

This analysis shows no significant main effects of NFC on either dependent variable, so neither Hypothesis H7 nor Hypothesis H8 is supported in this phase of analysis. However, the analysis for solution time indicates a significant interaction of NFC with problem complexity. Examination of the data shows that while solution times for the simpler problem were close for both high and low NFC subjects (14.6 versus 13.3 minutes, respectively), high NFC subjects took an average of about 21.3 minutes longer to solve the more complex problem, while low NFC subjects took an average of only 16.6 minutes longer These are independent groups, not repeated measures. This is opposite in direction from that hypothesized in H7, so this result does not support Hypothesis H7.

The method previously described for field dependence of dividing the sample into thirds and discarding the middle third was used to examine the NFC. No significant main effects nor interactions were identified using this technique.

As a final exploratory study of the NFC, a number of alternative splits of the sample were used, including 1/2 and one standard deviation above and below the sample mean. One of these appeared especially interesting, in which the sample was split at one standard deviation above the sample mean (a score of 126). With the sample thus categorized on NFC, a 2 X 2 X 2 full-factorial ANOVA was used to analyze the data. The results of this analysis are shown in Table 4-24 and Table 4-25.

TABLE 4-24
RESULTS OF NEED FOR COGNITION
(SPLIT AT ONE STD DEV ABOVE MEAN)
ANOVA FOR SOLUTION TIME (minutes)

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	12828.1	1	12828.1	271.61	.000
GIS availability (B)	392.1	1	392.1	8.30	.005
Need for cognition (C)	32.2	1	32.2	0.68	.411
A X B	118.9	1	118.9	2.52	.115
A X C	7.8	1	7.8	0.17	.685
B X C	29.7	1	29.7	0.63	.429
A X B X C	30.7	1	30.7	0.65	.422
Residual	6328.7	134	47.2		
Total	19780.9	141			

TABLE 4-25
RESULTS OF NEED FOR COGNITION
(SPLIT AT ONE STD DEV ABOVE MEAN)
ANOVA FOR SOLUTION PERCENT ERROR

SOURCE	*SS*	*df*	*MS*	*F*	*p*
Problem complexity (A)	79.0	1	79.0	0.84	.361
GIS availability (B)	1659.5	1	1659.5	17.68	.000
Need for cognition (C)	833.7	1	833.7	8.88	.003
A X B	15.8	1	15.8	0.17	.683
A X C	55.4	1	55.4	0.59	.444
B X C	463.7	1	463.7	4.94	.028
A X B X C	323.9	1	323.9	5.38	.065
Residual	12580.1	134	93.9		
Total	16114.7	141			

These results, albeit interesting, are surprising. A significant (*post facto*) main effect is observed for NFC on accuracy, and a significant (*post facto*) interaction between NFC and availability of GIS. However, the direction of the main effect difference is opposite that stated in Hypothesis H8. The data related to the interaction indicate that very high NFC (i.e., NFC score > 125) subjects experienced on average about a three times higher percent error than subjects with lower NFC, both with and without GIS. Thus neither Hypothesis H7 nor Hypothesis H8 is supported.

Assuming a medium effect size and using the tables from Cohen (1988), the ANOVA for need for cognition has a statistical power of about 0.69.

Independent sample t-test comparisons of means

As was the case with the analysis of field dependence, the preceding ANOVA for need for cognition included a fairly severely unbalanced design because of unequal cell sizes. Therefore, independent sample t-tests of means were studied for additional support of the results of the ANOVA. The t-test does not require a balanced design to be effective. The results of these t-tests are shown in Tables 4-26 through 4-29.

TABLE 4-26
INDEPENDENT SAMPLES T-TEST OF SOLUTION TIME FOR HIGH VERSUS LOW NFC ON LOW COMPLEXITY PROBLEM

				Pooled Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS lower NFC	31	13.4	3.04	1.08	.788	1.15	36	.129
GIS high NFC	7	11.9	3.12					
no GIS lower NFC	29	15.0	8.93	1.86	.403	1.62	35	.403
no GIS high NFC	8	13.1	23.28					

TABLE 4-27
INDEPENDENT SAMPLES T-TEST OF SOLUTION TIME FOR HIGH VERSUS LOW NFC ON HIGH COMPLEXITY PROBLEM

				Separate Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS lower NFC	26	29.8	7.19	3.36	.023	-.37	8.32	.360
GIS high NFC	8	31.6	13.19					
no GIS lower NFC	30	36.0	10.44	150.8	.013	1.94	36	.031
no GIS high NFC	3	32.2	0.85					

TABLE 4-28
INDEPENDENT SAMPLES T-TEST OF PERCENT ERROR
FOR HIGH VERSUS LOW NFC
ON LOW COMPLEXITY PROBLEM

				Pooled Variance Estimate				
Group	*N*	*Mean*	*Std Dev*	*F*	*p*	*t*	*df*	*1-tail p*
GIS lower NFC	31	0.0	0.00					
				*	*	.00	36	1.000
GIS high NFC	7	0.0	0.00					
				Separate Variance Estimate				
no GIS lower NFC	29	4.6	12.51					
				5.44	.001	-1.53	7.72	.083
no GIS high NFC	8	20.8	29.19					

* *F-value is undefined due to zero variance in the GIS case*

TABLE 4-29
INDEPENDENT SAMPLES T-TEST OF PERCENT ERROR
FOR HIGH VERSUS LOW NFC
ON HIGH COMPLEXITY PROBLEM

Group	*N*	*Mean*	*Std Dev*	*Separate Variance Estimate* *F*	*p*	*t*	*df*	*1-tail p*
GIS lower NFC	26	2.1	3.02					
				3.13	.033	-1.60	8.42	.073
GIS high NFC	8	5.3	5.34					
				Pooled Variance Estimate				
no GIS lower NFC	30	8.0	7.28					
				2.52	.196	-.58	31	.284
no GIS high NFC	3	10.7	11.55					

These results support those of the ANOVA for need for NFC, albeit in a more limited fashion than was desired. A significant difference was found for the solution time ($p<.05$) between high NFC and lower NFC subjects for the more complex problem without GIS. Weaker significance ($p<.10$) was found for differences in percent error between these classes of subjects for the more complex problem with GIS, and for the less complex problem without GIS. These results serve to lessen any concern about possible problems caused by the unbalanced design of the ANOVA for NFC.

Summary of results

Analysis of the experimental data yielded significant results. The primary thesis of the study, encompassed in hypotheses H1 and H2, was fully supported. Use of a GIS was shown to improve subjects' performance on a spatial task, as evidenced by lower solution times and higher accuracy. These results were consistent across two levels of problem complexity.

Only weak support was found that there is an interaction of GIS usage with problem complexity, as was hypothesized in H3 and H4. GIS usage may lessen the rate of solution time increase with problem complexity ($p < .10$) across the two levels of problem complexity used for the study. No such interaction was found for accuracy.

Field dependence was found to be related to task performance. Two relationships were hypothesized, in H5 and H6, to relate field dependence with solution time and accuracy, respectively. Support was found for H5, that higher field dependent people have higher solution times for the task. No support was found for H6, that high field dependence would mean lower accuracy for the task.

Need for cognition (NFC) was found to be related to task performance. Two relationships were hypothesized, in H7 and H8, to relate need for cognition with solution time and accuracy, respectively. Neither hypothesis was supported as stated. However, the results of the experiment showed significant relationships in the opposite direction from that stated in H7 and H8. A significant interaction of need for cognition with problem complexity indicated that high NFC people took significantly longer to complete the task than lower NFC people. A main effect of NFC on accuracy indicated that high NFC people had a significantly higher percent error than lower NFC people.

Table 4-30 summarizes the results of the analysis. Chapter 5 discusses the importance and relevance of these findings in detail.

TABLE 4-30
SUMMARY OF ANALYSIS FINDINGS

HYPOTHESIS	*OUTCOME*
H1: Solution time reduced by GIS	Supported
H2: Solution accuracy increased by GIS	Supported
H3: GIS lessens rate of time increase with problem complexity	Not supported (1)
H4: GIS lessens rate of accuracy decrease with problem complexity	Not supported
H5: Direct relationship of solution time to field dependence	Supported
H6: Direct relationship of solution accuracy to field dependence	Not supported
H7: Inverse relationship of solution time to need for cognition	Not supported (2)
H8: Direct relationship of solution accuracy to need for cognition	Not supported (3)

(1) Findings were not significant at the desired probability level of $p<.05$, but they are significant if the threshold is relaxed to $p<.10$ (not done for this study).
(2) Significant results were obtained in the opposite direction of the hypothesis, as evidenced by an interaction of need for cognition with problem complexity.
(3) Significant results were obtained in the opposite direction of the hypothesis, as evidenced by a main effect of need for cognition when the subjects were split into categories at one standard deviation above the sample mean.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

This study makes a needed contribution to theory and practice in the area of decision-maker performance gains related to use of a geographic information system (GIS) as a decision support aid. As stated in Chapter 1, GIS is a rapidly emerging technology which shows considerable promise as a decision support aid when the decisions to be made involve spatial information. Much of the information used in business has either explicit or implicit spatial components, such as addresses of customers, distribution of market segments, locations of mobile inventory and equipment, relevant political and regulatory zone boundaries, distribution and transportation networks, and many others. Even though GIS has become readily available to both private and public organizations to manage and analyze such a myriad of spatial information, there has been a lack of basic research about the contributions of GIS to improved decision-making.

By examining how two major components of decision-making, decision time and accuracy, vary with the use of a GIS, this study contributes to knowledge about the value of such systems. This approach is congruent with that recommended by previous research in information systems (Jarvenpaa & Dickson, 1988; Jarvenpaa, 1989; Hoadley, 1990). This study found that the addition of GIS to the decision environment reduced decision time and increased accuracy for both of the problem complexity levels used in the study.

In addition to basic knowledge about the effect of GIS usage on decision-maker performance, this study also makes a contribution in the area of the relationship of task performance to individual cognitive style for the type of task used in the experiment. This is, once again, congruent with recommendations from earlier research (Ives, 1982 and Liberatore, Titus, & Dixon, 1988). This study found that high field dependence is related to longer solution times, and that there is a significant interaction between field dependence and problem complexity. Subjects with a high need for cognition experienced a lower accuracy than the others, and there was an interaction between need for cognition and usage of a GIS.

Finally, this study provides the basis for proposing an extension to the taxonomy of image theory as originally put forth by Bertin (1983). The term *metafiguration* is proposed to describe a level of graphic image complexity beyond those of images and figurations originally proposed by Bertin. The study incorporated Bertin's (1983) taxonomy of Image Theory (IT) in the following manner. The decision criteria to be considered by each experimental subject was represented in one of two ways. In the first way, representing the traditional method of decision-making with maps, the subjects were provided with a series of paper maps and tabular information. Some of the criteria could be represented on two maps which were considered jointly, representing a simple figuration in IT. Other criteria required a series of three or more paper maps for the evaluation. These represented more complex figurations in IT. The overall problem required an even higher level of figuration which resulted, when using the paper maps, in a complex figuration of simpler figurations. The term *metafiguration* is proposed here for such a presentation.

With the addition of the GIS the nature of this metafiguration changes. The tabular data are incorporated into shaded thematic maps. The GIS allows the constituent figurations of the metafiguration to be collapsed into images. This results in a figuration represented by a collection of images, rather than a metafiguration consisting of a figuration of figurations. According to IT, images represent simpler, and thus more efficient, graphic displays, so the figurations derived from the GIS should be more efficient than metafigurations derived from the paper maps and tabular data. In this study this increase in efficiency was assumed to be measurable as decreases in problem solution times and increases in accuracy.

Review of results

Use of a GIS was shown to improve subjects' performance on a spatial task. This was evidenced by consistently lower solution times and higher accuracy across two levels of problem complexity.

There was weak evidence of an interaction of GIS usage with problem complexity. GIS usage may lessen the rate of solution time increase with problem complexity ($p < .10$) across the two levels of problem complexity used for the study. No such interaction was found for accuracy.

Highly field dependent people had higher solution times for the task, but field dependence was not significantly related to accuracy. High need for cognition (NFC) people had a significantly lower accuracy than lower NFC people. A significant interaction of need for cognition with GIS availability indicated that the tendency for high NFC people to be less accurate was moderated by use of the GIS, such that high NFC people with GIS experienced higher accuracy than other high NFC people without GIS.

Interpreting the variations in time and accuracy

The elapsed time of each subject to do the task used in the experiment was captured automatically by the computer used by the subject. Since some subjects used a GIS as a decision aid and some did not, it was necessary to determine comparable and appropriate start and end times for both settings. For consistency and control purposes, the timing began when a subject removed the main problem packet from an envelope to begin reading it, and it stopped when the subject finished recording all answers in the computer. This meant that the recorded time included some minimum amount, a sort of problem overhead, which was unaffected by whether the subject used a GIS or not, such as reading and comprehending the problem statement and recording answers in the database. However, differences in cognitive style may have influenced the amount of time spent in these overhead activities. Therefore, an analysis technique which considers all the identified factors of the experiment, such as a full factorial ANOVA, is appropriate for interpreting these data. This study found significant differences in time for the use of a GIS regardless of whether cognitive style was considered, but other researchers extending or replicating this work should keep this consideration in mind.

In contrast, accuracy has no such overhead associated with it. Accuracy may be separately and independently or interactively influenced by the task characteristics (complexity or availability of a GIS) and/or individual cognitive style (field dependence, need for cognition, or others). In this study, the error was expressed as a percentage. Percent error means were fairly modest, with the highest mean percent error being below nine percent. Any observed reductions in percent error would then push the mean toward an absolute minimum which is anchored at zero percent.

In a study such as this one, any factor which is found to reduce time or increase accuracy will also reduce variance of these two variables. Time will tend to reduce toward and cluster around the minimum overhead time. Percent error will tend to reduce toward zero. For example, for the low complexity problem in this study the percent error variance actually reduced to zero, at no errors, when GIS was added. This did not adversely affect the analysis in this study, but other researchers using similar techniques should be mindful of the potential for such shifts in variance and interpret their analysis results accordingly.

Conclusions

This section presents conclusions about the relationships of the four independent variables on the performance of individual decision-makers: use versus nonuse of a GIS, interaction of GIS with task complexity, individual field dependence, and individual need for cognition.

GIS use

The study found unequivocal evidence that addition of GIS technology to the decision environment for a spatial decision task reduced the decision time and increased the accuracy of individual decision-makers. This evidence has both theoretical and practical significance.

Using a GIS enabled decision-makers to complete the task in less time, possibly for three reasons. First, the GIS provided interactive, color graphical displays of the information rather than only the static, black-and-white information provided to subjects who had no GIS. Benbasat & Dexter (1985, 1986), Benbasat, Dexter & Todd (1986a, 1986b) and Hoadley (1988, 1990) found differences in performance related to type of display are to be expected. The present study is congruent with the prior research in this regard.

Second, and probably more importantly, the GIS provided more efficient displays, in accordance with image theory (IT). Bertin (1983) provided a taxonomy in IT for categorizing graphical displays as either images or figurations. An image is a minimum graphical form which is singly sufficient to answer a question posed about the information it contains. More complex data and concepts may require more complex graphical representations involving two or more images in order to answer a particular question. These collections of images to answer certain questions are called figurations in IT, and are inherently less efficient than images for answering such questions, according to IT. Subjects using only paper maps and tabular information had to solve parts of the task using figurations. Subjects using GIS, on the other hand, were able to use images for the same parts because the GIS essentially collapsed the figurations into images. The resulting images were simpler and more efficient than the figurations used by subjects who had no GIS. The results obtained in the study bear this out.

Third, the more efficient (and perhaps more interesting) information presentation afforded by the GIS enabled a better grasp of the task due to better visualization of the problem to be solved. This in turn contributed to greater performance efficiencies for subjects. The importance of problem visualization is discussed by Venkatesh and Verville (1991).

These efficiencies predicted by IT also should increase the accuracy of subjects. This was shown to be true in this study. Although Bertin (1983) did not specifically address accuracy in his discussion of images and figurations in IT, Jarvenpaa (1989), Jarvenpaa & Dickson (1988), and Hoadley (1990) have pointed out the need and desirability of including both time and accuracy in any study related to the performance of decision-makers using graphical information. Therefore, the conclusions of these researchers may be combined with those of IT with regard to graphic display efficiency.

By taking an integrated approach and including both time and accuracy as components of graphical display efficiency, this study has shown that a GIS makes positive contributions to decision-maker performance, as evidenced by lower solution times and greater accuracy.

Interaction of GIS with task complexity

This author has considerable practitioner experience in the design and use of GIS for problem solving. An interesting observation during much of this experience was an apparent increase in human problem solving capacity associated with the use of a GIS. It appeared, from informal observation, that users of a GIS actually improved their problem solving capacity for the type of problem addressed by the GIS. One outcome of this effect seemed to be that the GIS users experienced a lower performance penalty (i.e., increase in time, decrease in accuracy) associated with more complex problems than nonusers of GIS. This in turn implies some interaction of GIS usage and task complexity.

This study provided some evidence for the hypothesized interaction of GIS usage and task complexity, but the findings are not conclusive at the desired level of significance. If the interaction does exist, then it probably has its greatest effect on solution time. The interaction was significant for solution time at a level of $p<.10$, but this was insufficient to draw firm conclusions from the present study.

It is possible that, while the two levels of task complexity employed in this study were sufficient to observe the main effects of GIS usage and problem complexity, they may have encompassed too little difference in problem complexity to observe the hypothesized interaction. A later study will extend the present one by adding an additional level of complexity which is expected to test this interaction more adequately .

This interaction, if it can be shown to be significant in the later study, may hold considerable importance for practitioners. Vendors of GIS are quick to point out the anticipated efficiency gains a purchaser may expect when implementing a GIS. This study has shown that there are performance gains associated with the use of GIS. However, an interaction of GIS usage and task complexity could indicate that GIS usage enables decision-makers to extend the range of problem complexity that may be addressed. GIS usage may facilitate solution of problems that were not solvable using previous manual methods. This was actually observed by the author in previous practitioner experience. Further study is warranted to validate and quantify this observation.

Field dependence

Field dependence has been included in a number of information systems studies as an independent variable related to performance. Its inclusion in this study seemed especially appropriate since the process experienced by subjects on the measurement instrument, the Group Embedded Figures Test (Witkin et al., 1971), seemed to closely approximate the extraction of information from the types of maps used in this study. From this observed similarity it was hypothesized that a subject's level of field dependence should be a good measure of how he or she might perform on the task. This was found to be true for decision time.

In studies by Liberatore, Titus, & Dixon (1988) and Benbasat & Dexter (1985), the approach to analyze field dependence was to split the subjects into two groups, above and below the sample mean. Liberatore, Titus, & Dixon reported no significant differences in decision accuracy related to field dependence; however, they did not record decision time. In contrast, Benbasat & Dexter (1985) found significant differences in decision accuracy related to field dependence, and no significant differences in decision time related to field dependence.

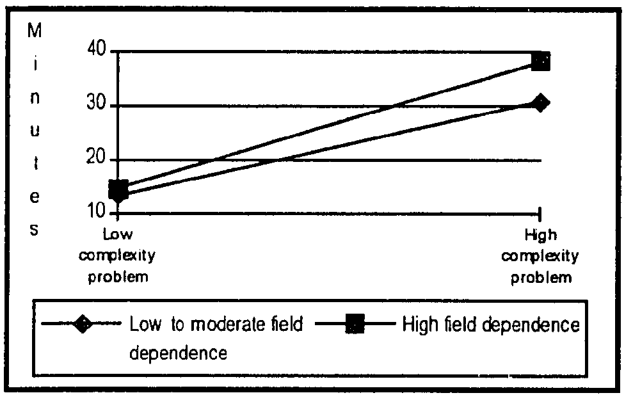
The present study found significant differences in decision time related to field dependence, and no significant differences in accuracy related to field dependence. There may be at least two explanations of the apparent partial contradiction of this study's results with those of previous research with respect to field dependence.

First, this study, after exploratory analysis, split the subjects into two groups at one-half standard deviation below the sample mean, rather than at the sample mean as in the other two studies. Therefore, this study considered differences between *very* field dependent people and all the rest of the sample.

Second, the sample sizes in the Liberatore, Titus, & Dixon (1988) and Benbasat & Dexter (1985) studies were only 23 and 35, respectively, while the present study had a sample size of 142. Thus, the previous two studies may have had insufficient statistical power to properly differentiate the effects under study.

A significant interaction of field dependence with problem complexity on solution time was observed in this study. While low field dependence subjects solved the problem in less time for both levels of problem complexity, the difference was much greater for the higher complexity problem. This ordinal interaction is illustrated in Figure 5-1.

FIGURE 5-1
INTERACTION OF FIELD DEPENDENCE WITH PROBLEM COMPLEXITY FOR SOLUTION TIME



The observed interaction indicates that low-to-moderate field dependent people experienced less of an increase in decision time (that is, a performance penalty) than highly field dependent people when problem complexity was increased.

Therefore, for decisions involving graphical representations of spatial information, high field dependence is associated with longer solution times, and field dependence is not related to accuracy. In addition, high field dependence is associated with a greater performance penalty (in time) as problem complexity is increased.

Need for cognition

Examination of need for cognition (NFC) provided an interesting enigma. Subjects with a high NFC were hypothesized to experience shorter solution times and higher accuracy. NFC was not found to be related to solution time. However, NFC was found to be significantly related to accuracy, but with an *opposite* relationship from that hypothesized. Subjects with a high NFC experienced a *lower* accuracy than the other subjects.

There are at least two possible explanations for this finding. First, the NFC questionnaire instrument may not elicit the intended responses from certain people. There may be other cognitive style factors which elicit high NFC-like responses from subjects who do not truly have a high NFC. There is presently no evidence to support such a conjecture, however.

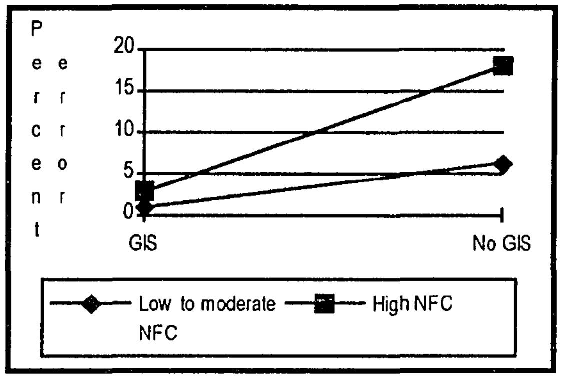
A second explanation is that high NFC people approached the experimental task with so much thoughtful consideration that they made the problem more difficult than it actually was. In other words, they thought too hard about the problem. Some support for this explanation is found in Cohen, Stotland, & Wolfe (1955), who described NFC as a need to structure relevant situations in meaningful, integrated ways, and as a need to understand and make reasonable the experiential world. Cohen (1957) found that individuals with high NFC are more likely to organize, elaborate on, and evaluate the information to which they are exposed.

The NFC hypotheses assumed that such additional organizing, elaborating, and evaluating by high NFC subjects would lead to a higher level of performance (i.e., lower decision times and higher accuracy) on the task. It may be that, in actuality, the additional work load that the high NFC subjects imposed on themselves actually exacted a performance penalty. This seems to be the most likely explanation of the two, even though there was observed only a performance penalty for accuracy, and none for time.

Such a performance penalty may only exist for tasks which are unfamiliar to subjects. If the subjects were already familiar with the task then they would not experience the need to expend the additional mental effort to better understand the problem. They would have already done so in order to become familiar with the task. Thus, high NFC may contribute to higher task performance only for familiar tasks.

An interaction of NFC with GIS usage was observed. While high NFC subjects experienced a lower accuracy regardless of whether the GIS was used, the accuracy was much lower without GIS than with GIS. Figure 5-2 shows a plot of the means and the nature of this ordinal interaction, which implies that a GIS lowers the performance penalty experienced by high NFC people on unfamiliar tasks.

FIGURE 5-2
INTERACTION OF NEED FOR COGNITION WITH
GIS USAGE FOR PERCENT ERROR



High NFC people experience lower accuracy than moderate to low NFC people for unfamiliar tasks involving graphical representations of spatial information. Adding a GIS to the decision-making environment increases accuracy for high NFC people.

Limitations

This study has at least two limitations. First, the task was specialized, thus the results may not be generalizable to other less specialized tasks, although at least some generalizability to other *spatial* tasks is expected.

Second, the subjects were college sophomores. Generalizability of results obtained using such surrogate decision-makers has been questioned by Gordon, Slade, & Schmitt (1986). However, the validity of using sophomores as surrogates for more experienced decision-makers has been defended by Greenberg

(1987). Additional work is required to confirm the validity of using sophomores as surrogate decision-makers for spatial tasks.

Future directions

This study points to additional research which should be undertaken. Of most interest at the present time is further exploration of the hypothesized interaction of GIS usage with problem complexity. Because the present study did lend some support for the interaction, extending the study by using another level of complexity would more fully test this interaction. If more complexity were designed into the task, then this interaction should show significant differences.

The study should be repeated or extended using more mature decision-makers. An extension to this study using graduate students or practitioners as subjects is planned to test the effects of age and experience.

In the course of this study, additional data related to accuracy were collected from each subject for later analysis. That is, the point value assigned by each subject to each site based on each criterion was captured as part of the data collection. Analysis of these data would indicate what types of displays showed the lowest accuracy across the subjects, and how the task and individual characteristics relate to differences in accuracy.

Additionally, a post-task questionnaire was administered to each subject to assess such factors as decision-maker confidence, user process satisfaction, and individual level of motivation for the problem. Analysis of these data is needed to relate the factors to the task and individual characteristics.

Finally, this study has established a task environment and experimental methodology which can be applied to other similar tasks. Additional tasks should be developed and tested in order to test the generalizability of the results of the present study.

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APPENDICES

Appendix 1: Subject demographic questionnaire

Please tell us a little about yourself:

Your participant ID number from labels (NOT student ID): _____
Your age: _______ years Your sex: ___F ___M
Standing: __Freshman __Sophomore __Junior __Senior __Grad
Your intended major: ____

Please answer the following questions:
1. Prior to taking K201 did you have any experience using computers?
___Yes ___No
2. Have you ever had to use a computer as part of a job you've held?
___Yes ___No
If yes, what was your job title:______________________________
& please give a brief description of how you used a computer:
____

3. OTHER THAN just retrieving information (like finding a book at the library) or word processing, have you ever used a computer to solve a real problem you were working on or were concerned with?
___Yes ___No
If yes, please briefly describe the problem(s) you've used a computer for solving:
____

4. Have you ever had to read and/or interpret maps or land surveys as a part of a job you've held?
___Yes ___No
If yes, what was your job title:______________________________
& please briefly describe the problem(s) you've used maps or land surveys for solving:
____

5. OTHER THAN using common road maps and/or world globes for driving places or satisfying simple curiosity questions, have you ever used maps or land surveys to solve some type of real problem you were working on or concerned with?
___Yes ___No
Please briefly describe of how you used maps or land surveys:
____

Appendix 2: Need for cognition questionnaire

Do not agree at all								Agree completely
1	2	3	4	5	6	7	8	9

1 I would prefer complex to simple problems.
2 I like to have the responsibility of handling a situation that requires a lot of thinking.
3 Thinking is not my idea of fun.
4 I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.
5 I try to anticipate and avoid situations where there a likely chance I will have to think in depth about something.
6 I find satisfaction in deliberating hard and for long hours.
7 I only think as hard as I have to.
8 I prefer to think about small, daily projects to long-term projects.
9 I like tasks that require little thought once I've learned them.
10 The idea of relying on thought to make my way to the top appeals to me.
11 I really enjoy a task that involves coming up with new solutions to problems.
12 Learning new ways to think doesn't excite me very much.
13 I prefer my life to be filled with puzzles that I must solve.
14 The notion of thinking abstractly is appealing to me.
15 I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.
16 I feel relief rather than satisfaction after completing a task that required a lot of mental effort.
17 It's enough for me that something gets the job done; I don't care how or why it works.
18 I usually end up deliberating about issues even when they do not affect me personally.

after Cacioppo & Petty (1982)

Appendix 3: Practice problem

Practice problem statement for group without GIS

Western Hughes Corporation (WHC) is planning to build an incinerator in the Bloomington area to dispose of PCB wastes which are currently in landfills in various parts of Monroe County. It has narrowed its search to two possible sites. Two criteria are now to be used to prioritize the two sites in order of preference for the incinerator.

You, as a senior operations analyst, have just been assigned the job of determining the priority ranking of the two sites. You will use a point system to evaluate each site on each of the two criteria. The site which receives the most points will be assigned a priority rank of 1, and the one with the least points will receive a priority rank of 2.

You have available to you the enclosed maps showing the locations of the factors of the criteria. Use the following guidelines to assign points to the sites:

1. **Roads**. To get the material to the incinerator, adequate roads for the trucks is mandatory. The company can build a short access road, but for economic reasons the new site should be within 2 miles of a major road. If a site is within 2 miles of a road, give it 4 points. If not, it gets no points for roads.

2. **Environmentally sensitive area**. The shaded area shown on the map is known to be especially sensitive to activities like the incinerator. WHC prefers to build the incinerator outside this area. If a site is outside this area, give it 3 points. If it is inside the area, it gets no points.

Your task is to evaluate the project and assign a priority rank to each site being considered. You will enter the criteria points and the priority rank for each site in the following tables. Then enter the same information in the computer scoring system.

Scoring of Sites

Enter the point total for each site

	A	B
Roads		

Guideline: No points if *more* than 2 miles from a road; 4 points if *less* than 2 miles from a road.

	A	B
Environmental Area		

Guideline: No points if *inside* the environmental area; 3 points if *outside* the environmental area.

Ranking of Sites

Enter RANK number, NOT point totals!

	A	B
Ranking for each Site		

Guideline: Enter Priority Rank number (1 or 2) of each site.

Practice problem statement for group with GIS

Western Hughes Corporation (WHC) is planning to build an incinerator in the Bloomington area to dispose of PCB wastes which are currently in landfills in various parts of Monroe County. It has narrowed its search to two possible sites. Two criteria are now to be used to prioritize the two sites in order of preference for the incinerator.

You, as a senior operations analyst, have just been assigned the job of determining the priority ranking of the two sites. You will use a point system to evaluate each site on each of the two criteria. The site which receives the most points will be assigned a priority rank of 1, and the one with the least points will receive a priority rank of 2.

You have available to you the enclosed maps showing the locations of the factors of the criteria. In addition, the company has just installed a new computer-based map analysis system on your computer to help you. Use the following guidelines to assign points to the sites:

1. **Roads**. To get the material to the incinerator, adequate roads for the trucks is mandatory. The company can build a short access road, but for economic reasons the new site should be within 2 miles of a major road. If a site is within 2 miles of a road, give it 4 points. If not, it gets no points for roads.

2. **Environmentally sensitive area**. The shaded area shown on the map is known to be especially sensitive to activities like the incinerator. WHC prefers to build the incinerator outside this area. If a site is outside this area, give it 3 points. If it is inside the area, it gets no points.

Your task is to evaluate the project and assign a priority rank to each site being considered. You are to use the new computer-based map analysis system as your primary tool, but you are free to use the paper materials as much as you need, as well. You will enter the criteria points and the priority rank for each site in the following tables. Then enter the same information in the computer scoring system.

Scoring of Sites

Enter the point total for each site

	A	B
Roads		

Guideline: No points if *more* than 2 miles from a road; 4 points if *less* than 2 miles from a road.

	A	B
Environmental Area		

Guideline: No points if *inside* the environmental area; 3 points if *outside* the environmental area.

Ranking of Sites

Enter RANK number, NOT point totals!

	A	B
Ranking for each Site		

Guideline: Enter Priority Rank number (1 or 2) of each site.

Figure A3-1
Practice problem--sites map

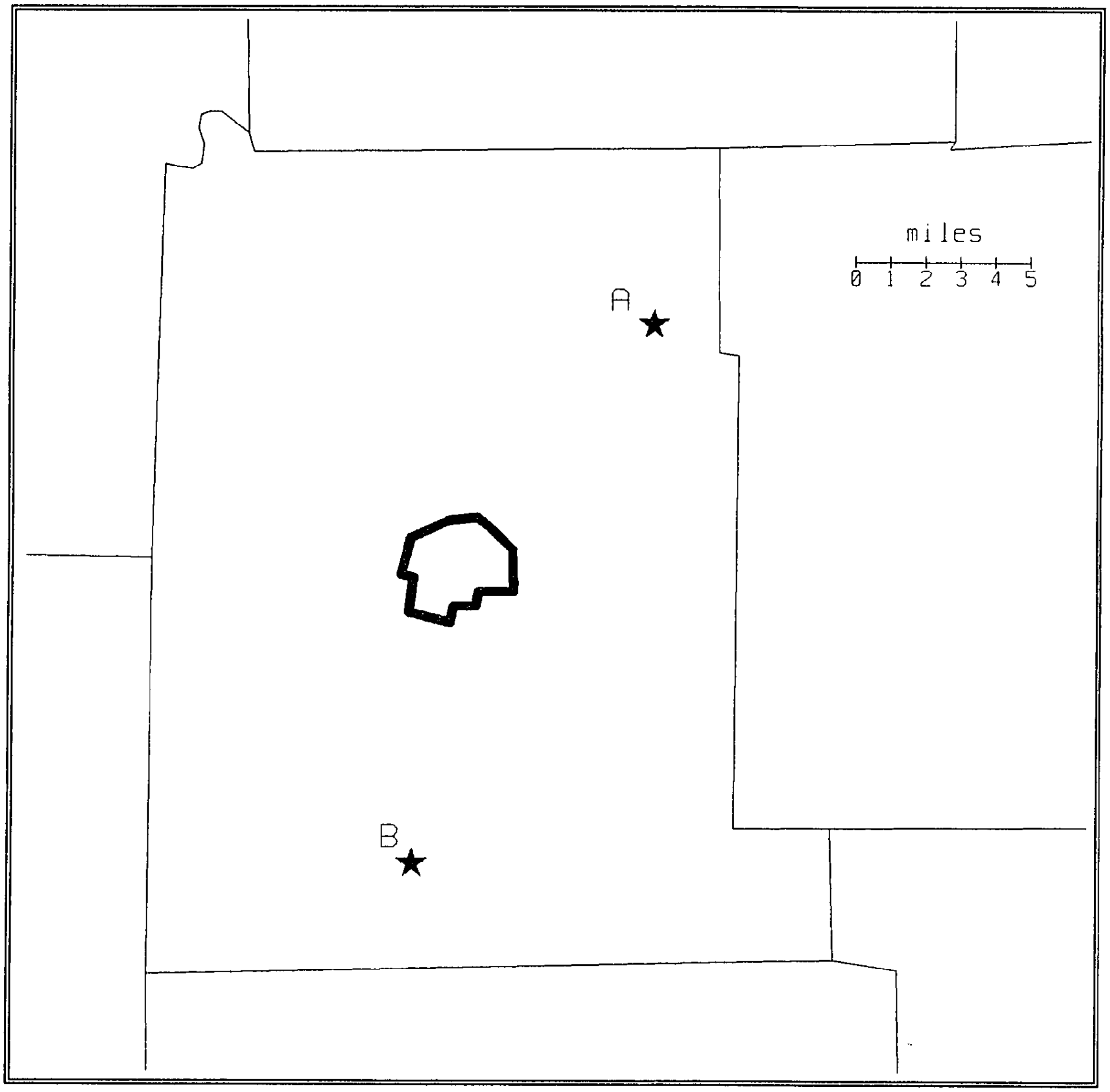

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Figure A3-2
Practice problem--roads criterion

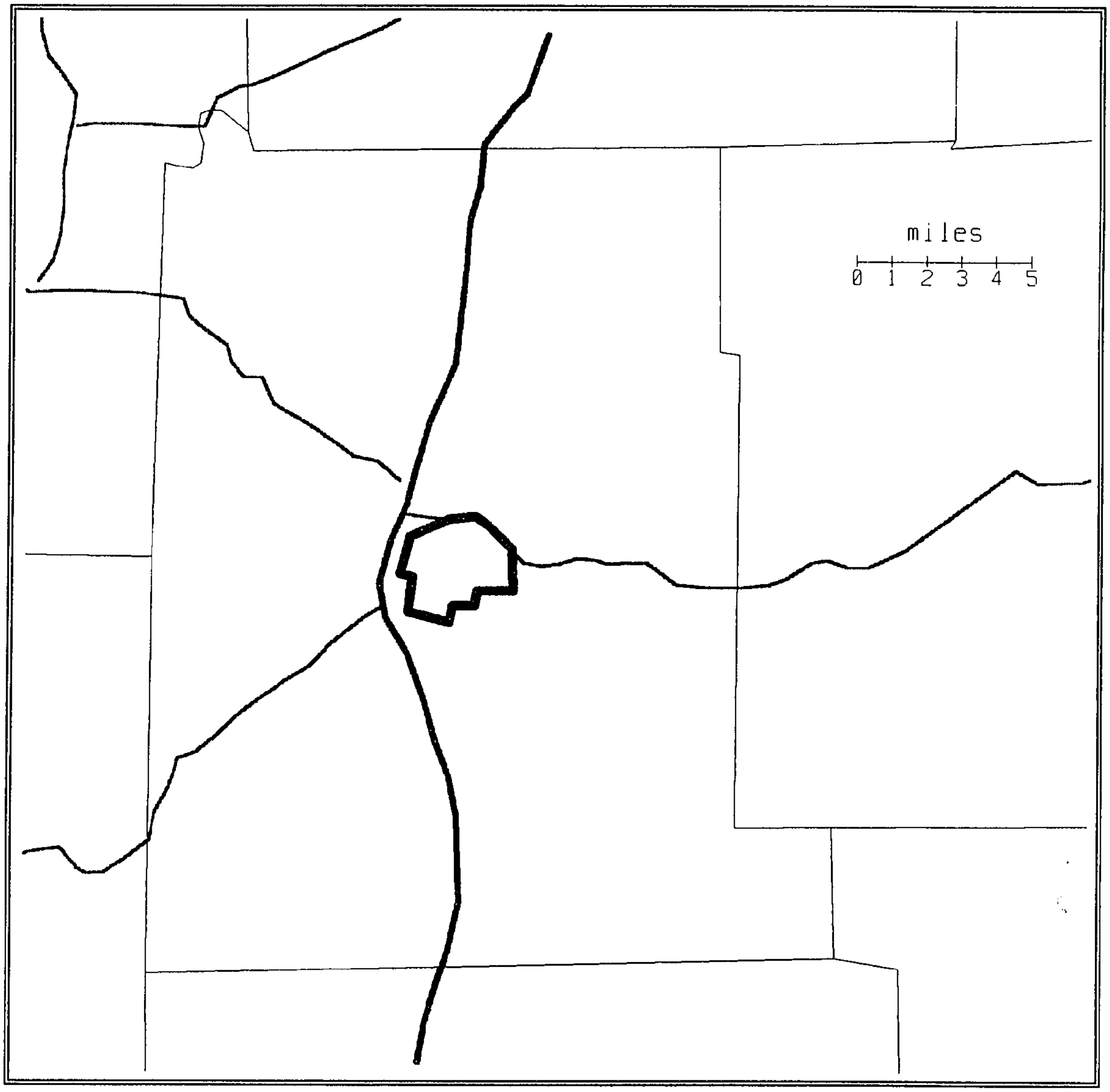

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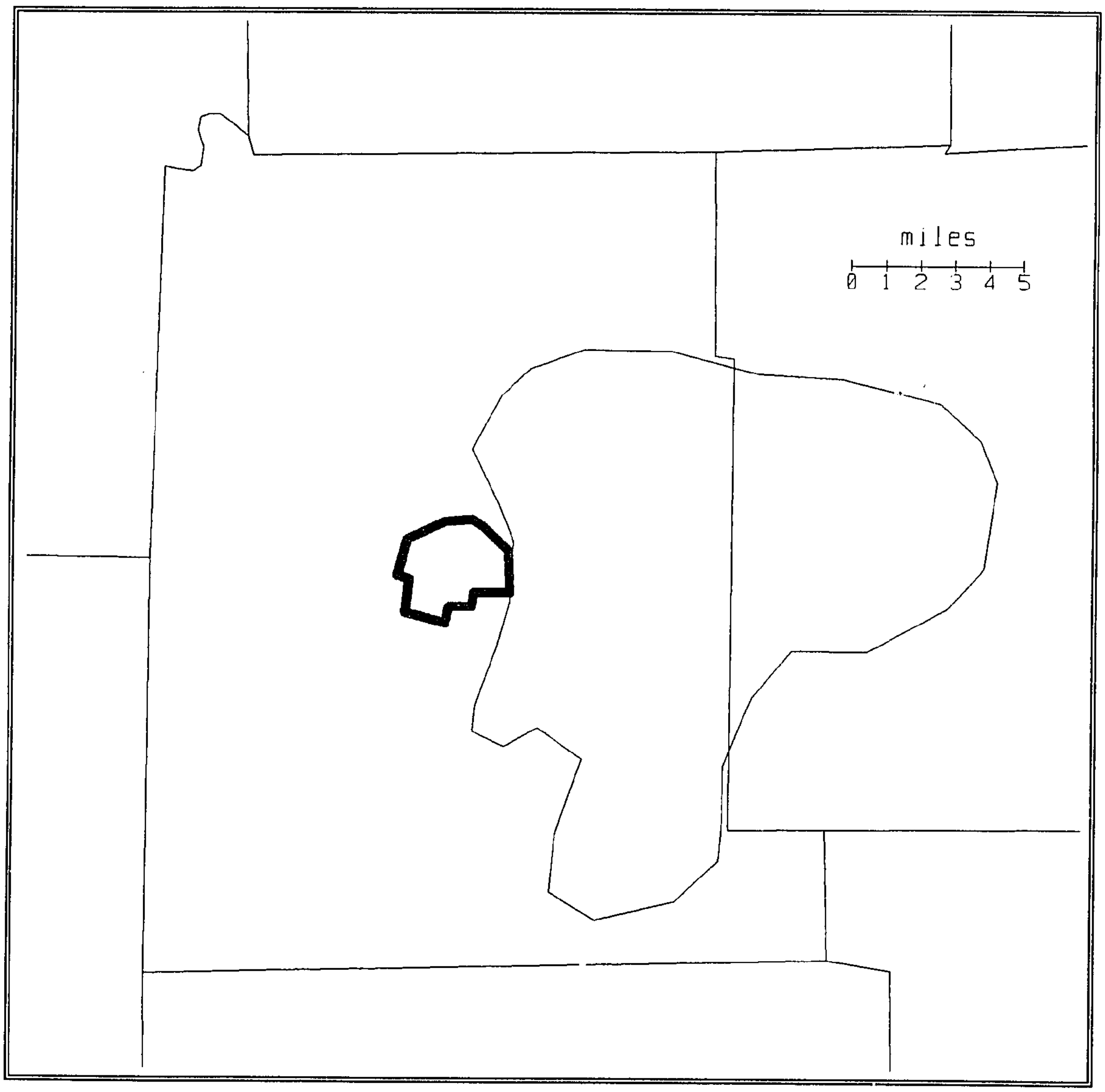
Figure A3-3
Practice problem--environmental area criterion



map reduced in size for publication

Figure A3-4
Practice problem--GIS screen for roads criterion

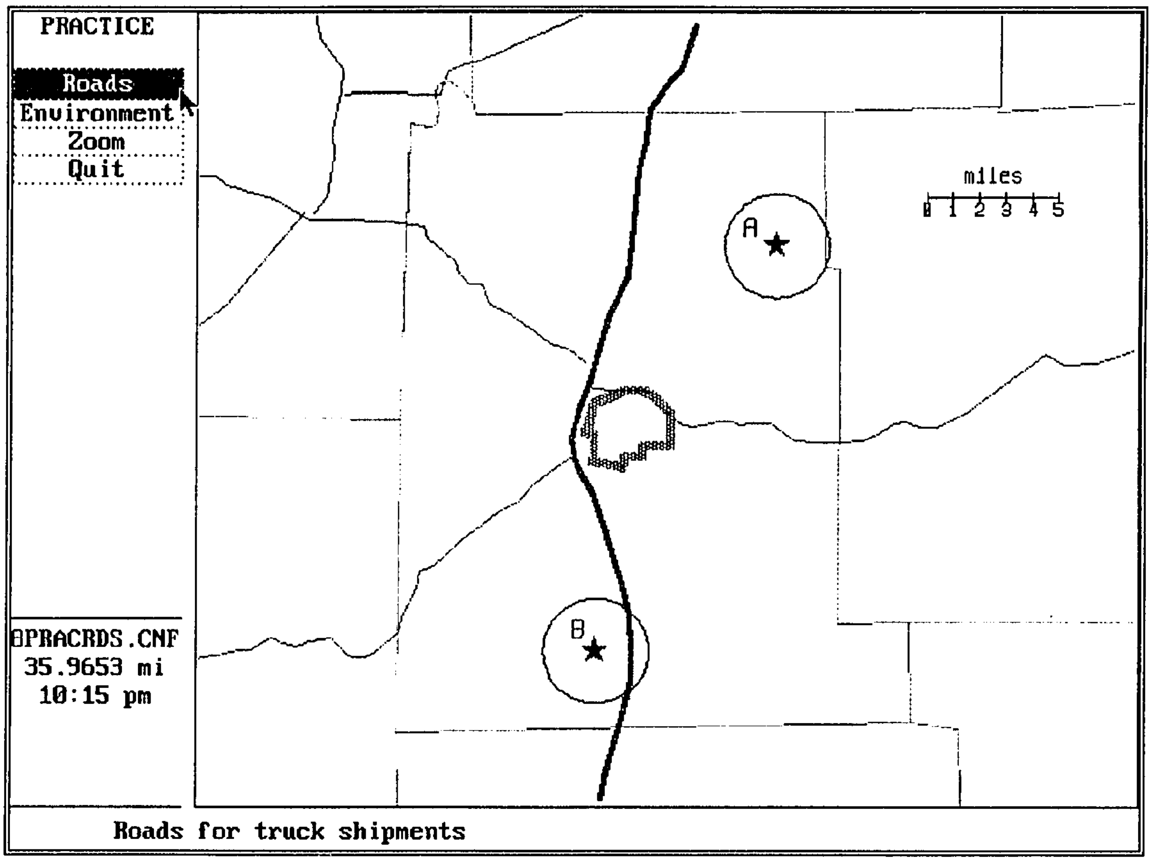
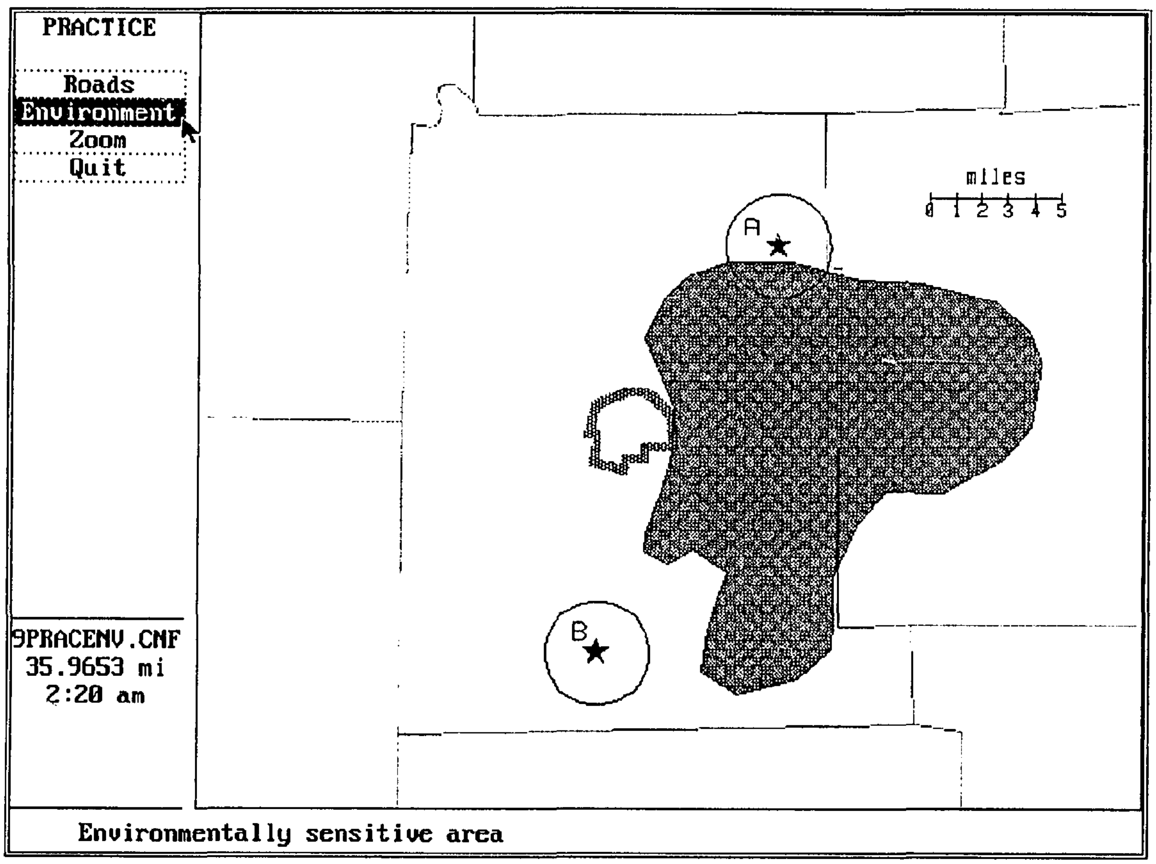


Figure A3-5
Practice problem--GIS screen for environmental area criterion



Appendix 4: Less complex main problem

Problem statement for group without GIS

Indiana Power and Electric (IPE) has learned of a new electric power generating technology, known as the fuel cell, which could revolutionize its business. It plans initially to replace a number of older coal-fired generator stations with the new fuel cells. It has identified several potential sites as candidates for replacement. Since IPE may be able to replace the generators in only a few sites in the near future, it now needs to prioritize the candidate sites by ranking them against several important criteria which have been identified by company experts.

You, as a senior operations analyst, have just been assigned the job of determining the priority ranking of the various sites. You will use a point system to evaluate each site against each of the criteria. The site which receives the most points will receive a priority rank of 1. The remaining sites will receive rankings of 2, 3, 4, etc. on the basis of decreasing point totals.

You have available to you the attached maps showing the locations of the various factors of the criteria. Use the following guidelines to assign points to the sites:

1. **Population.** To encourage cleaner rural electrification the state of Indiana has instituted a tax credit for installing the new fuel cells. The credit is tied to county population. Installation in a county of more than 50,000 population receives no tax credit, so assign zero points. A 25% tax credit is allowed if the county where the site is located has less than 50,000 population, so assign 5 points if this is true. An additional 10% tax credit is allowed if the county has less than 50,000 population and *all* Indiana counties which border that county also have less than 50,000 population. Assign a total of 8 points to the site if this is the case.

2. **Parks/Recreation Areas/Forests.** The coal-fired generators presently in use emit a high amount of pollutants into rivers and lakes and into the air. These effects are often noticed to a greater extent when they occur near parks, recreation areas, and the Hoosier National Forest. Since the new technology emits virtually no pollution the company would like to improve its public image by concentrating on sites near these areas. Assign a site 3 points if it is within 10 miles of one of these areas, and zero points if it is not.

3. **Politically Active Areas.** Certain areas in the state have a higher concentration of political activists concerned with the environment. The present focus of these activists is on reducing the concentrations of acidic pollutants near parks, recreation areas, and the Hoosier National Forest. In responding to this concern, IPE wishes to give priority to those sites which are within the activist concentration areas. If a site is outside these areas it gets zero points for this criteria. If it is within one of the political areas but over 10 miles from a park/recreation area/forest, give it 2 points. If it is within a politically active area *and* within 10 miles of a park/recreation area/forest, give it 4 points.

Your task is to evaluate the project using the provided maps and assign a priority rank to each site being considered. You will enter the criteria points and the priority rank for each site on the scoring sheet. Then enter the same information into the computer scoring system.

Problem statement for group with GIS

Indiana Power and Electric (IPE) has learned of a new electric power generating technology, known as the fuel cell, which could revolutionize its business. It plans initially to replace a number of older coal-fired generator stations with the new fuel cells. It has identified several potential sites as candidates for replacement. Since IPE may be able to replace the generators in only a few sites in the near future, it now needs to prioritize the candidate sites by ranking them against several important criteria which have been identified by company experts.

You, as a senior operations analyst, have just been assigned the job of determining the priority ranking of the various sites. You will use a point system to evaluate each site against each of the criteria. The site which receives the most points will receive a priority rank of 1. The remaining sites will receive rankings of 2, 3, 4, etc. on the basis of decreasing point totals.

You have available to you the attached maps showing the locations of the various factors of the criteria. In addition, the company has just installed a new computer-based map analysis system on your computer to help you. Use the following guidelines to assign points to the sites:

1. **Population.** To encourage cleaner rural electrification the state of Indiana has instituted a tax credit for installing the new fuel cells. The credit is tied to county population. Installation in a county of more than 50,000 population receives no tax credit, so assign zero points. A 25% tax credit is allowed if the county where the site is located has less than 50,000 population, so assign 5 points if this is true. An additional 10% tax credit is allowed if the county has less than 50,000 population and *all* Indiana counties which border that county also have less than 50,000 population. Assign a total of 8 points to the site if this is the case.

2. **Parks/Recreation Areas/Forests.** The coal-fired generators presently in use emit a high amount of pollutants into rivers and lakes and into the air. The these effects are often noticed to a greater extent when they occur near parks, recreation areas, and the Hoosier National Forest. Since the new technology emits virtually no pollution the company would like to improve its public image by concentrating on sites near these areas. Assign a site 3 points if it is within 10 miles of one of these areas, and zero points if it is not.

3. **Politically Active Areas.** Certain areas in the state have a higher concentration of political activists concerned with the environment. The present focus of these activists is on reducing the concentrations of acidic pollutants near parks, recreation areas, and the Hoosier National Forest. In responding to this concern, IPE wishes to give priority to those sites which are within the activist concentration areas. If a site is outside these areas it gets zero points for this criteria. If it is within one of the political areas but over 10 miles from a park/recreation area/forest, give it 2 points. If it is within a politically active area *and* within 10 miles of a park/recreation area/forest, give it 4 points.

Your task is to evaluate the project and assign a priority rank to each site being considered. You are to use the new computer-based map analysis system as your primary tool, but you are free to use the paper materials as much as you need, as well. You will enter the criteria points and the priority rank for each site on the scoring sheet. Then you will need enter the same information into the computer scoring system.

Scoring of Sites

Enter the point total for each site

	A	C	E	I	J
Population					

Guideline: No points if in a county *more* than 50,000 population;
5 points if in a county *less* than 50,000 population;
8 points if in a county *less* than 50,000 population
and all adjoining counties also *less* than 50,000 population.

	A	C	E	I	J
Recreation Areas					

Guideline: No points if *more* than 10 miles from Rec area/park/forest;
3 points if *less* than 10 miles from Rec area/park/forest.

	A	C	E	I	J
Recreation Areas/Politics					

Guideline: No points if *outside* a politically active area;
2 points if *more* than 10 miles from Rec area/park/forest
and inside a politically active area;
4 points if *less* than 10 miles from Rec area/park/forest
and inside a politically active area.

Ranking of Sites

Enter RANK number, NOT point totals!

	A	C	E	I	J
Rank for each Site					

Guideline: Enter Priority Rank number (1 thru 5) of each site.

Figure A4-1
Site location map

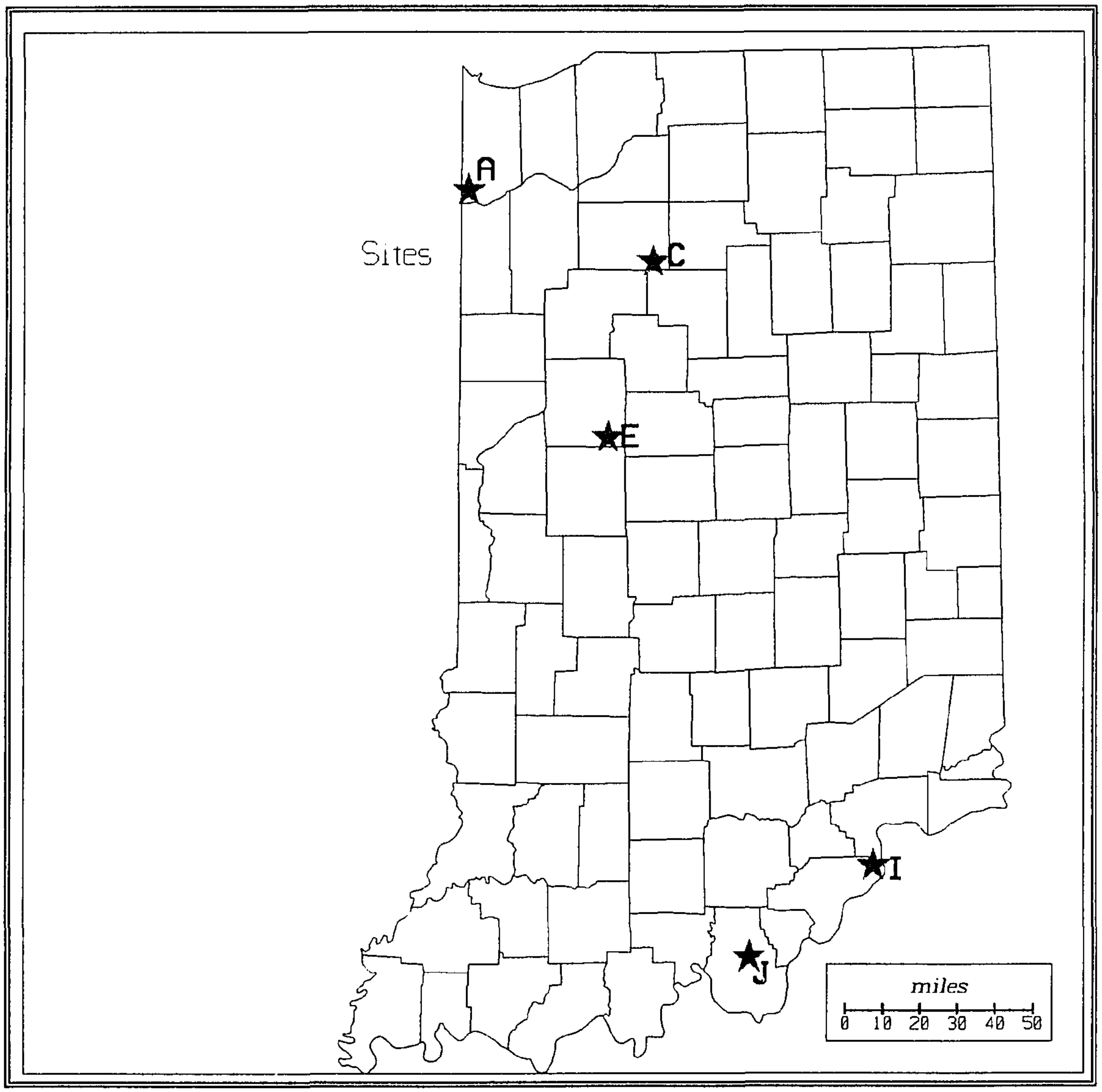


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Figure A4-2
County map

map reduced in size for publication

Figure A4-3
County populations table

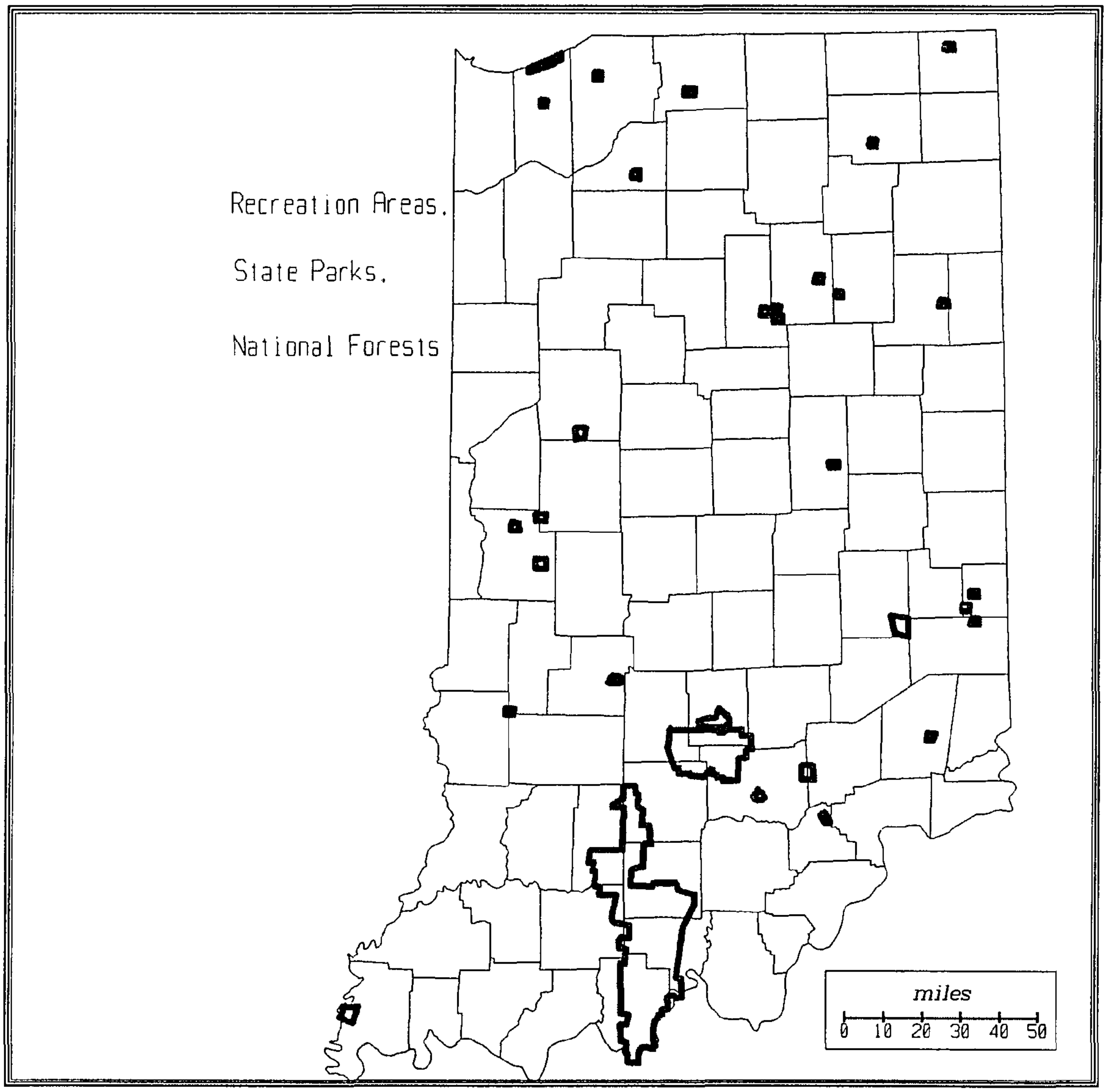
COUNTY	1990 Population
ADAMS	31,095
ALLEN	300,836
BARTHOLOMEW	63,657
BENTON	9,441
BLACKFORD	14,067
BOONE	38,147
BROWN	14,080
CARROLL	18,809
CASS	38,413
CLARK	87,777
CLAY	24,705
CLINTON	30,974
CRAWFORD	9,914
DAVIESS	27,533
DEARBORN	38,835
DECATUR	23,645
DEKALB	35,324
DELAWARE	119,659
DUBOIS	36,616
ELKHART	156,198
FAYETTE	26,015
FLOYD	64,404
FOUNTAIN	17,808
FRANKLIN	19,580
FULTON	18,840
GIBSON	31,913
GRANT	74,169
GREENE	30,410
HAMILTON	108,936
HANCOCK	45,527
HARRISON	29,890
HENDRICKS	75,717
HENRY	48,139
HOWARD	80,827
HUNTINGTON	35,427
JACKSON	37,730
JASPER	24,960

COUNTY	1990 Population
LAWRENCE	42,836
MADISON	130,669
MARION	797,159
MARSHALL	42,182
MARTIN	10,369
MIAMI	36,897
MONROE	108,978
MONTGOMERY	34,436
MORGAN	55,920
NEWTON	13,551
NOBLE	37,877
OHIO	5,315
ORANGE	18,409
OWEN	17,281
PARKE	15,410
PERRY	19,107
PIKE	12,509
PORTER	128,932
POSEY	25,968
PULASKI	12,643
PUTNAM	30,315
RANDOLPH	27,148
RIPLEY	24,616
RUSH	18,129
SCOTT	20,991
SHELBY	40,307
SPENCER	19,490
ST JOSEPH	247,052
STARKE	22,747
STEUBEN	27,446
SULLIVAN	18,993
SWITZERLAND	7,738
TIPPECANOE	130,598
TIPTON	16,119
UNION	6,976
VANDERBURGH	165,058
VERMILION	16,773

JAY	21,512
JEFFERSON	29,797
JENNINGS	23,661
JOHNSON	88,109
KNOX	39,884
KOSCIUSKO	65,294
LA PORTE	107,066
LAGRANGE	29,477
LAKE	475,594

VIGO	106,107
WABASH	35,069
WARREN	8,176
WARRICK	44,920
WASHINGTON	23,717
WAYNE	71,951
WELLS	25,948
WHITE	23,265
WHITLEY	27,651

Figure A4-4
Recreation areas map



map is reduced in size for publication

Figure A4-5
Politically active areas

map is reduced in size for publication

Appendix 5: More complex main problem

Problem statement--without GIS

Indiana Power and Electric (IPE) has learned of a new electric power generating technology, known as fuel cells, which could revolutionize its business. It plans initially to replace a number of older coal-fired generator stations with the new fuel cells. It has identified several potential sites as candidates for replacement. Since IPE may be able to replace the generators in only a few sites in the near future, it now needs to prioritize the candidate sites by ranking them against several important criteria which have been identified by company experts.

You, as a senior operations analyst, have just been assigned the job of determining the priority ranking of the various sites. You will use a point system to evaluate each site against each of the criteria. The site which receives the most points will receive a priority rank of 1. The remaining sites will receive rankings of 2, 3, 4, etc. on the basis of decreasing point totals.

You have available to you the attached maps showing the locations of the various factors of the criteria. Use the following guidelines to assign points to the sites:

1. **Population**. To encourage cleaner rural electrification the state of Indiana has instituted a tax credit for installing the new fuel cells. The credit is tied to county population. Installation in a county of more than 50,000 population receives no tax credit, so assign zero points. A 25% tax credit is allowed if the county where the site is located has less than 50,000 population, so assign 5 points if this is true. An additional 10% tax credit is allowed if the county has less than 50,000 population *and* all Indiana counties which border that county also have less than 50,000 population. Assign a total of 8 points to the site if this is the case.

2. **Natural Gas Pipelines**. The new fuel cells require natural gas, so a source of gas is imperative. Two pipeline companies have indicated availability of gas for the sites. IPE has determined that ANR Pipeline (ANR) has good gas availability for all the sites, while Texas Eastern (TE) has only fair availability. The pipeline used for a site must be within 10 miles of the site to be economic. If there is no pipeline within 10 miles of a site, assign zero points. If there is an ANR pipeline within 10 miles assign 7 points. If a TE pipeline is within 10 miles, assign 4 points. If there is both an ANR *and* a TE pipeline within 10 miles, assign 11 points.

3. **Parks/Recreation Areas/Forests**. The coal-fired generators presently in use emit a high amount of pollutants into rivers and lakes and into the air. The these effects are often noticed to a greater extent when they occur near parks, recreation areas, and the Hoosier National Forest. Since the new technology emits virtually no pollution the company would like to improve its public image by concentrating on sites near these areas. Assign a site 3 points if it is within 10 miles of one of these areas, and zero points if it is not.

4. **Endangered Darter Fish.** Rainwater runoff from the area of the present coal-fired generators is highly acidic and pollutes rivers and streams, threatening the fish population. Since the company wishes to be environmentally responsible it wants to place a higher priority on sites within areas where there are endangered fish species. If a site is within an endangered darter fish area give it 3 points, otherwise give it zero points for this criteria.

5. **Population and Major Market Interaction**. The fundamental economics of a site will be greatest if it is within a major market area of the company. This effect will be enhanced if the site is also in a high-population county (over 50,000). Assign zero points for this criteria if the site is not in a major market area. Assign 2 points if a site is inside a major market but within a county of less than 50,000 population. If the site is within a major market area *and* in a county of more than 50,000 population, assign 4 points.

6. **Politically Active Areas.** Certain areas in the state have a higher concentration of political activists concerned with the environment. The present focus of these activists is on reducing the concentrations of acidic pollutants near parks, recreation areas, and the Hoosier National Forest. In responding to this concern, IPE wishes to give priority to those sites which are within the activist concentration areas. If a site is outside these areas it gets zero points for this criteria. If it is within one of the political areas but over 10 miles from a park/recreation area/forest, give it 2 points. If it is within a politically active area *and* within 10 miles of a park/recreation area/forest, give it 4 points.

7. **Flying Endangered Species.** The air pollution from the coal-fired generators is believed to have negative effects on certain flying animals. This factor is particularly important for endangered species such as the Indiana Bat and certain birds, including Herons and Whooping Cranes. The evidence for these effects is not very strong, however, so IPE wishes to emphasize this criteria only when multiple endangered species areas overlap. For this criteria we will consider the total environmental contribution, including the darter fish evaluated earlier. If a site is within none or only one of the three endangered species areas, this criteria gets zero points. If the site is within any two of the areas, assign 3 points. If the site is within all three endangered species areas, assign 6 points.

Your task is to evaluate the project using the provided maps and assign a priority rank to each site being considered. You will enter the criteria points and the priority rank for each site on the scoring sheet. Then enter the same information into the computer scoring system.

Problem statement--with GIS

Indiana Power and Electric (IPE) has learned of a new electric power generating technology, known as fuel cells, which could revolutionize its business. It plans initially to replace a number of older coal-fired generator stations with the new fuel cells. It has identified several potential sites as candidates for replacement. Since IPE may be able to replace the generators in only a few sites in the near future, it now needs to prioritize the candidate sites by ranking them against several important criteria which have been identified by company experts.

You, as a senior operations analyst, have just been assigned the job of determining the priority ranking of the various sites. You will use a point system to evaluate each site against each of the criteria. The site which receives the most points will receive a priority rank of 1. The remaining sites will receive rankings of 2, 3, 4, etc. on the basis of decreasing point totals.

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2. **Natural Gas Pipelines**. The new fuel cells require natural gas, so a source of gas is imperative. Two pipeline companies have indicated availability of gas for the sites. IPE has determined that ANR Pipeline (ANR) has good gas availability for all the sites, while Texas Eastern (TE) has only fair availability. The pipeline used for a site must be within 10 miles of the site to be economic. If there is no pipeline within 10 miles of a site, assign zero points. If there is an ANR pipeline within 10 miles assign 7 points. If a TE pipeline is within 10 miles, assign 4 points. If there is both an ANR *and* a TE pipeline within 10 miles, assign 11 points.

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4. **Endangered Darter Fish**. Rainwater runoff from the area of the present coal-fired generators is highly acidic and pollutes rivers and streams, threatening the fish population. Since the company wishes to be environmentally responsible it wants to place a higher priority on sites within areas where there are endangered fish species. If a site is within an endangered darter fish area give it 3 points, otherwise give it zero points for this criteria.

5. **Population and Major Market Interaction**. The fundamental economics of a site will be greatest if it is within a major market area of the company. This effect will be enhanced if the site is also in a high-population county (over 50,000). Assign zero points for this criteria if the site is not in a major market area. Assign 2 points if a site is inside a major market but within a county of less than 50,000 population. If the site is within a major market area *and* in a county of more than 50,000 population, assign 4 points.

6. **Politically Active Areas**. Certain areas in the state have a higher concentration of political activists concerned with the environment. The present focus of these activists is on reducing the concentrations of acidic pollutants near parks, recreation areas, and the Hoosier National Forest. In responding to this concern, IPE wishes to give priority to those sites which are within the activist concentration areas. If a site is outside these areas it gets zero points for this criteria. If it is within one of the political areas but over 10 miles from a park/recreation area/forest, give it 2 points. If it is within a politically active area *and* within 10 miles of a park/recreation area/forest, give it 4 points.

7. **Flying Endangered Species**. The air pollution from the coal-fired generators is believed to have negative effects on certain flying animals. This factor is particularly important for endangered species such as the Indiana Bat and certain birds, including Herons and Whooping Cranes. The evidence for these effects is not very strong, however, so IPE wishes to emphasize this criteria only when multiple endangered species areas overlap. For this criteria we will consider the total environmental contribution, including the darter fish evaluated earlier. If a site is within none or only one of the three endangered species areas, this criteria gets zero points. If the site is within any two of the areas, assign 3 points. If the site is within all three endangered species areas, assign 6 points.

Your task is to evaluate the project and assign a priority rank to each site being considered. You are to use the new computer-based map analysis system as your primary tool, but you are free to use the paper materials as much as you need, as well. You will enter the criteria points and the priority rank for each site on the scoring sheet. Then enter the same information into the computer scoring system.

Scoring of Sites

Enter the point score for each site

	A	B	C	D	E	F	G	H	I	J
Population										

Guideline: No points if in a county with *more* than 50,000 population;
5 points if in a county with *less* than 50,000 population;
8 points if in a county with *less* than 50,000 population
and all adjoining counties also *less* than 50,000 population.

	A	B	C	D	E	F	G	H	I	J
Pipelines										

Guideline: No points if *more* than 10 miles from *any* pipeline;
4 points if *less* than 10 miles from a *fair* availability pipeline (TE);
7 points if *less* than 10 miles from a *good* availability pipeline (ANR);
11 points if *less* than 10 miles from a *fair* availability pipeline (TE) *and*
less than 10 miles from a *good* availability pipeline (ANR).

	A	B	C	D	E	F	G	H	I	J
Recreation Areas										

Guideline: No points if *more* than 10 miles from any Rec area/park/forest;
3 points if *less* than 10 miles from a Rec area/park/forest.

	A	B	C	D	E	F	G	H	I	J
Darter Fish										

Guideline: No points if *outside* an endangered darter fish area;
3 points if *inside* an endangered darter fish area.

(Continued on other side)

Scoring of Sites

(continued from other side)

	A	B	C	D	E	F	G	H	I	J
Population /Major Markets										

Guideline: No points if *outside* a major market area;
2 points if *less* than 50,000 population
and inside a major market area;
4 points if *more* than 50,000 population in county
and inside a major market area.

	A	B	C	D	E	F	G	H	I	J
Recreation Areas/Politics										

Guideline: No points if *outside* a politically active area;
2 points if *more* than 10 miles from Rec area/park/forest
and inside a politically active area;
4 points if *less* than 10 miles from Rec area/park/forest
and inside politically active area.

	A	B	C	D	E	F	G	H	I	J
Endangered Species										

Guideline: Include darter fish, birds, and bats.
No points if *not inside at least two* endangered species areas;
3 points if *inside any two* endangered species areas;
6 points if *inside all three* endangered species areas.

Ranking of Sites

Enter RANK number, NOT point totals!

	A	B	C	D	E	F	G	H	I	J
Rank for each Site										

Guideline: Enter Priority Rank number (1 thru 10) of each site.

Figure A5-1
Site location map

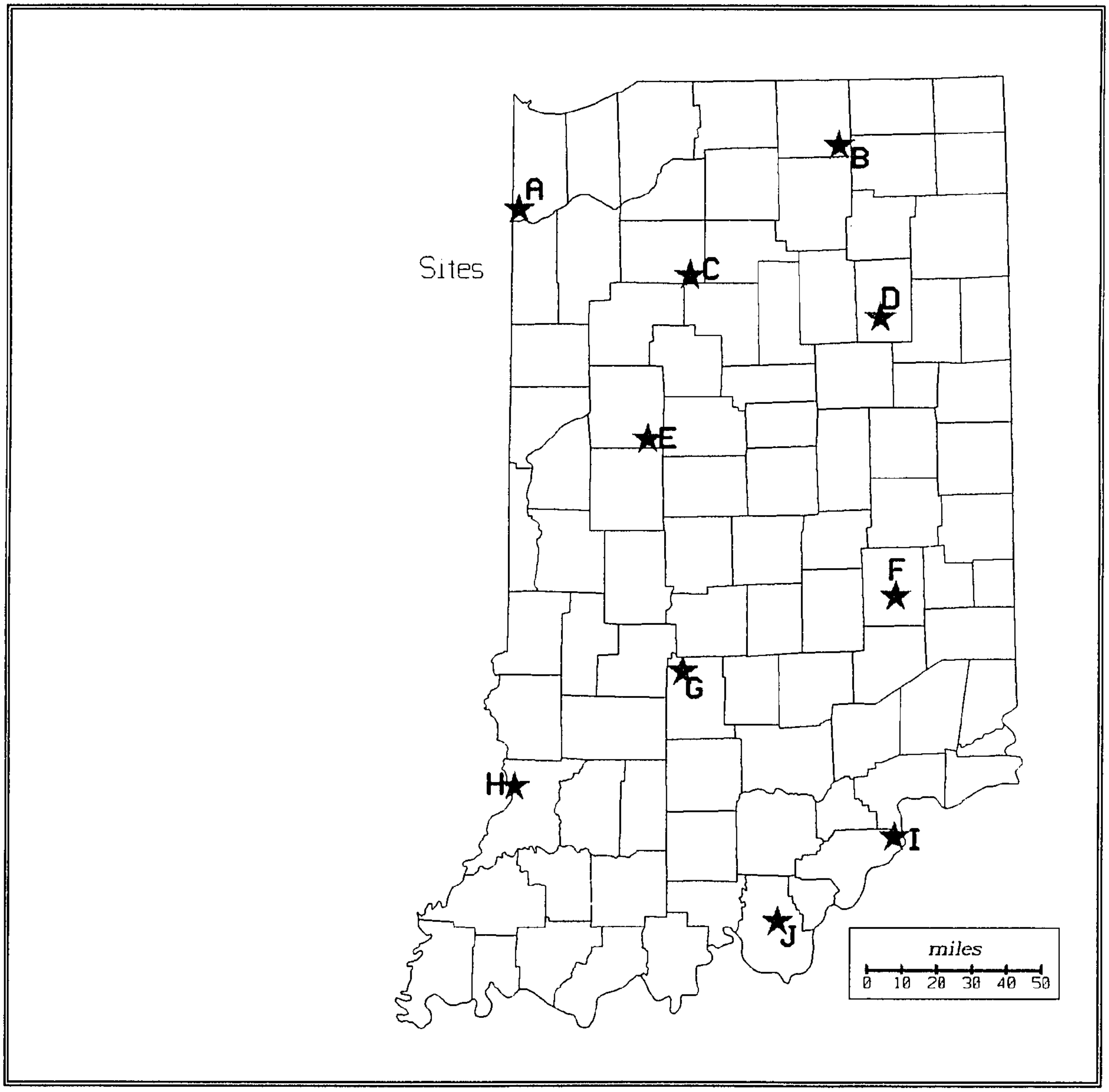


Figure A5-2
County map

Figure A5-3
County populations table

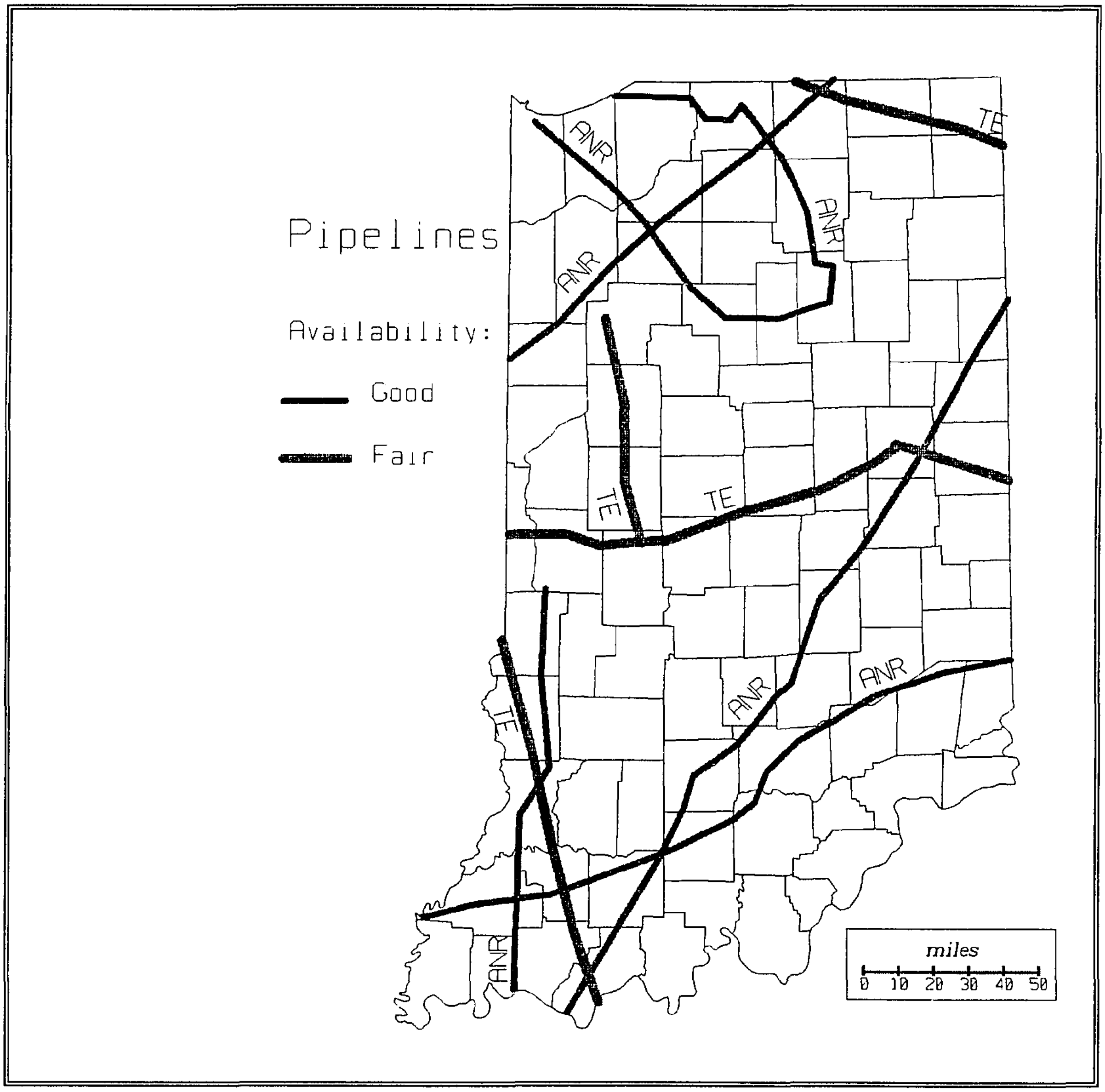
COUNTY	1990 Population
ADAMS	31,095
ALLEN	300,836
BARTHOLOMEW	63,657
BENTON	9,441
BLACKFORD	14,067
BOONE	38,147
BROWN	14,080
CARROLL	18,809
CASS	38,413
CLARK	87,777
CLAY	24,705
CLINTON	30,974
CRAWFORD	9,914
DAVIESS	27,533
DEARBORN	38,835
DECATUR	23,645
DEKALB	35,324
DELAWARE	119,659
DUBOIS	36,616
ELKHART	156,198
FAYETTE	26,015
FLOYD	64,404
FOUNTAIN	17,808
FRANKLIN	19,580
FULTON	18,840
GIBSON	31,913
GRANT	74,169
GREENE	30,410
HAMILTON	108,936
HANCOCK	45,527
HARRISON	29,890
HENDRICKS	75,717
HENRY	48,139
HOWARD	80,827
HUNTINGTON	35,427
JACKSON	37,730
JASPER	24,960
JAY	21,512

COUNTY	1990 Population
LAWRENCE	42,836
MADISON	130,669
MARION	797,159
MARSHALL	42,182
MARTIN	10,369
MIAMI	36,897
MONROE	108,978
MONTGOMERY	34,436
MORGAN	55,920
NEWTON	13,551
NOBLE	37,877
OHIO	5,315
ORANGE	18,409
OWEN	17,281
PARKE	15,410
PERRY	19,107
PIKE	12,509
PORTER	128,932
POSEY	25,968
PULASKI	12,643
PUTNAM	30,315
RANDOLPH	27,148
RIPLEY	24,616
RUSH	18,129
SCOTT	20,991
SHELBY	40,307
SPENCER	19,490
ST JOSEPH	247,052
STARKE	22,747
STEUBEN	27,446
SULLIVAN	18,993
SWITZERLAND	7,738
TIPPECANOE	130,598
TIPTON	16,119
UNION	6,976
VANDERBURGH	165,058
VERMILION	16,773
VIGO	106,107

JEFFERSON	29,797
JENNINGS	23,661
JOHNSON	88,109
KNOX	39,884
KOSCIUSKO	65,294
LA PORTE	107,066
LAGRANGE	29,477
LAKE	475,594

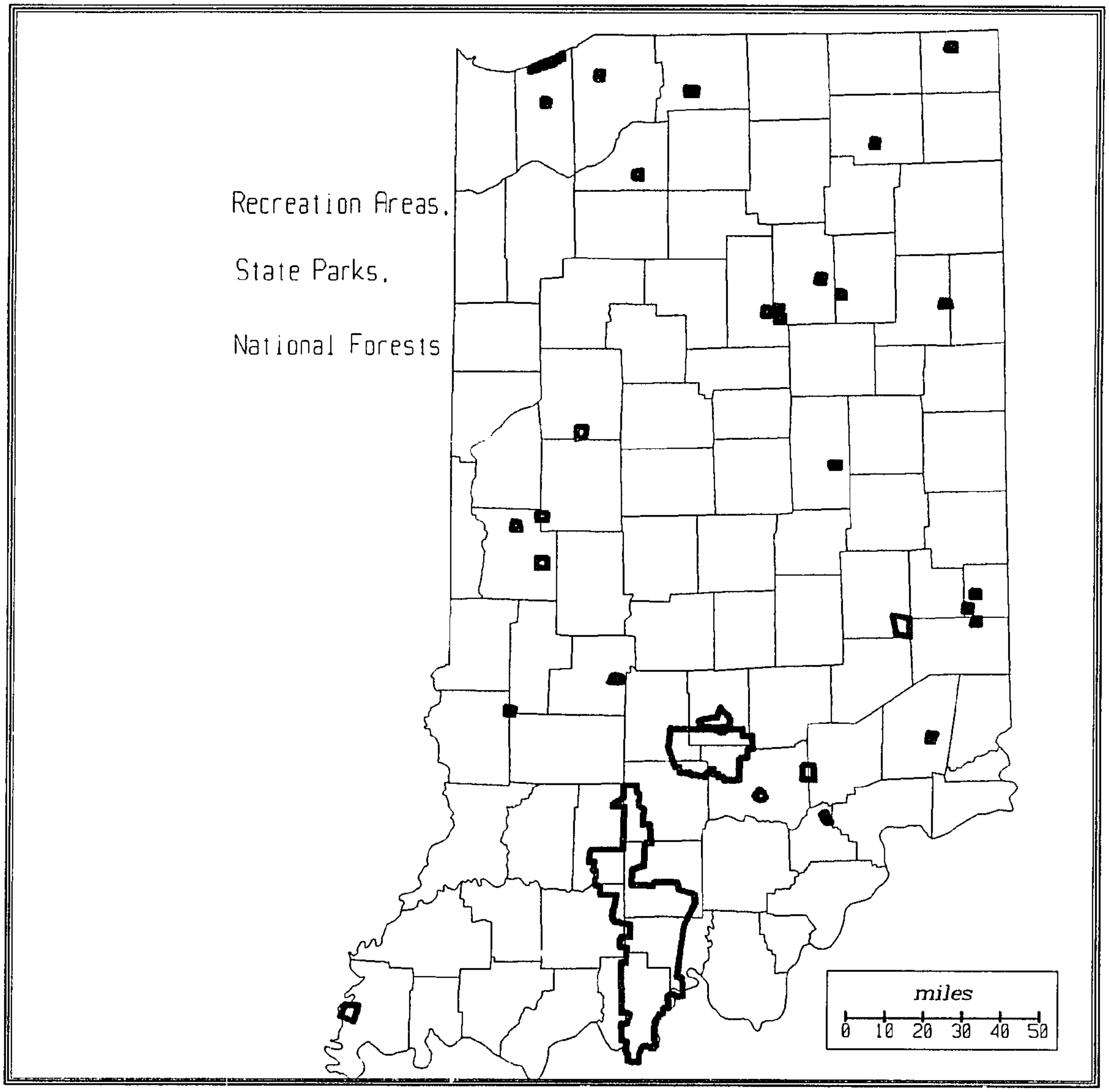
WABASH	35,069
WARREN	8,176
WARRICK	44,920
WASHINGTON	23,717
WAYNE	71,951
WELLS	25,948
WHITE	23,265
WHITLEY	27,651

Figure A5-4
Pipelines map



map is reduced in size for publication

Figure A5-5
Recreation areas map



map is reduced in size for publication

Figure A5-6
Endangered fish areas map

map is reduced in size for publication

Figure A5-7
Major market areas map

map is reduced in size for publication

Figure A5-8
Politically active areas map

map is reduced in size for publication

Figure A5-9
Endangered bats areas map

map is reduced in size for publication

Figure A5-10
Endangered birds areas map

map is reduced in size for publication

Appendix 6: GIS screens, less complex problem

Figure A6-1
Less Complex Problem, Population Criterion Screen

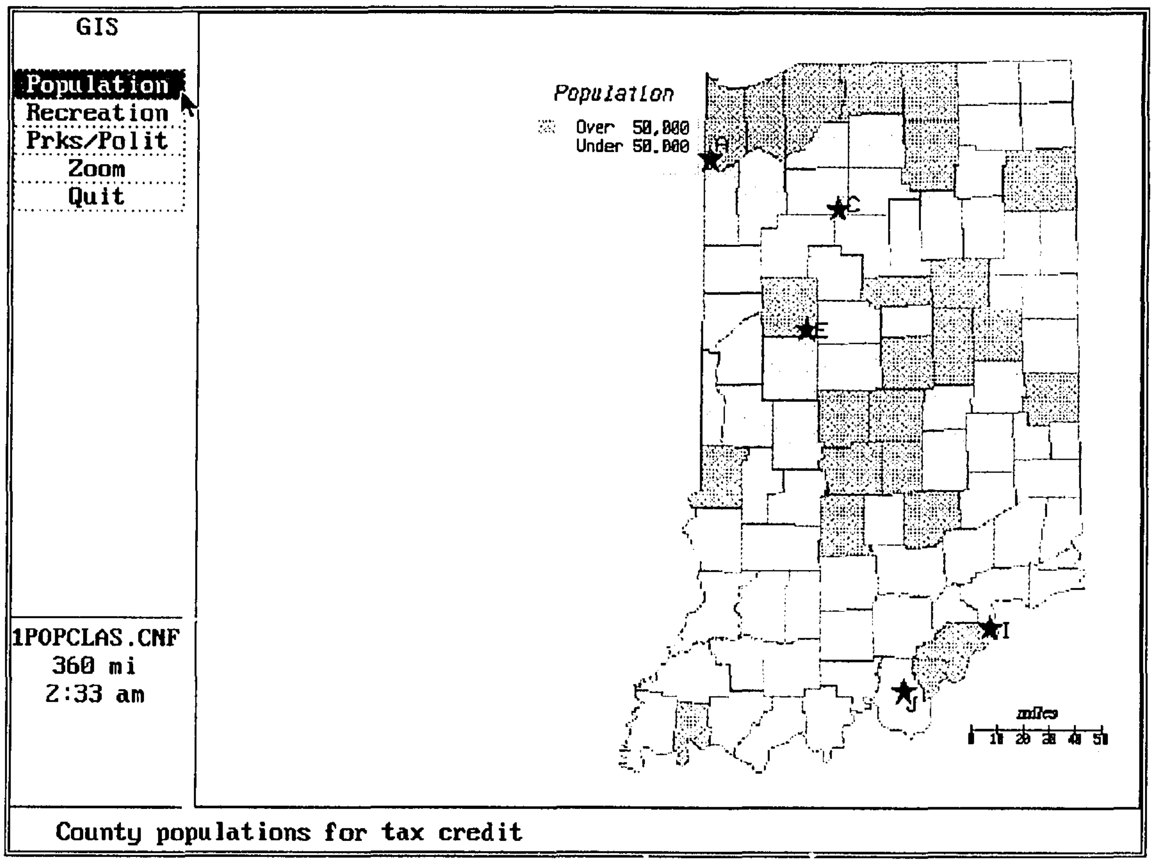


Figure A6-2
Less Complex Problem, Recreation Areas Criterion Screen

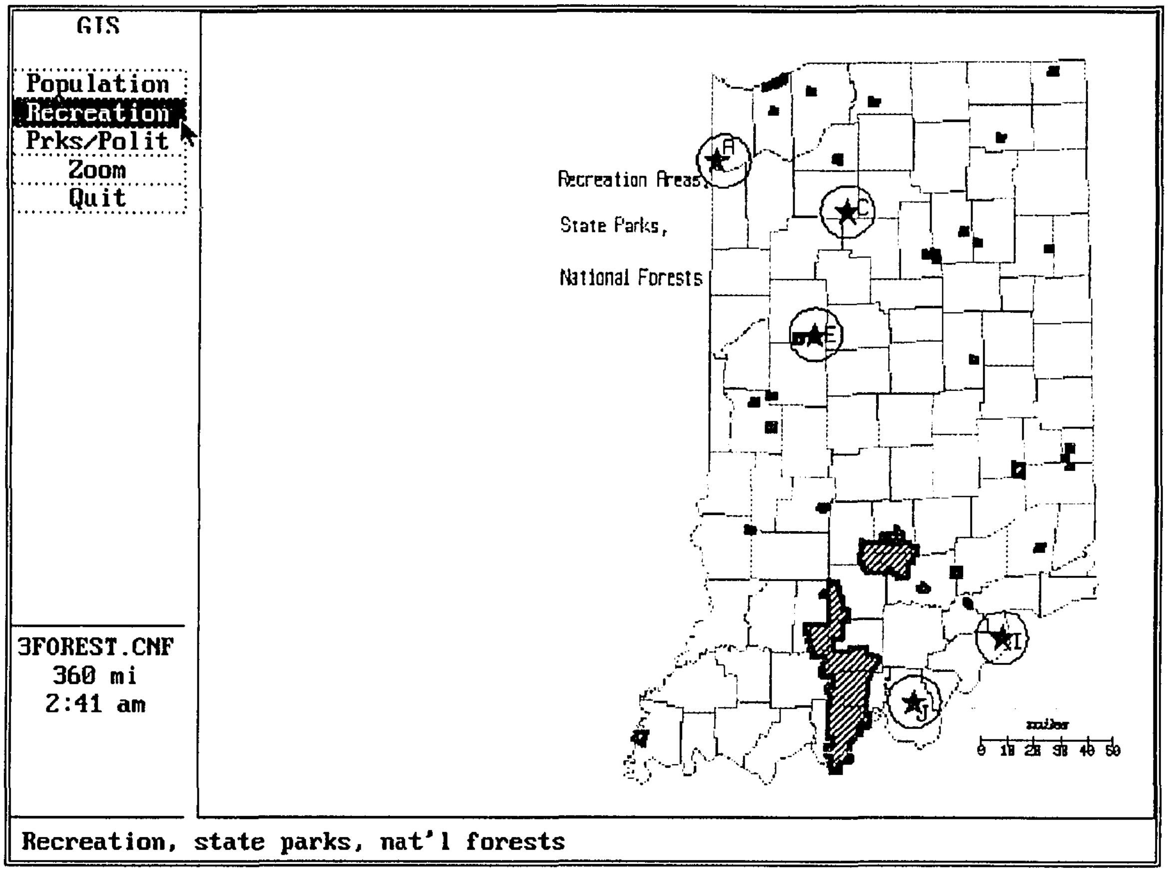


Figure A6-3
Less Complex Problem, Recreation/Politically Active Areas Criterion Screen

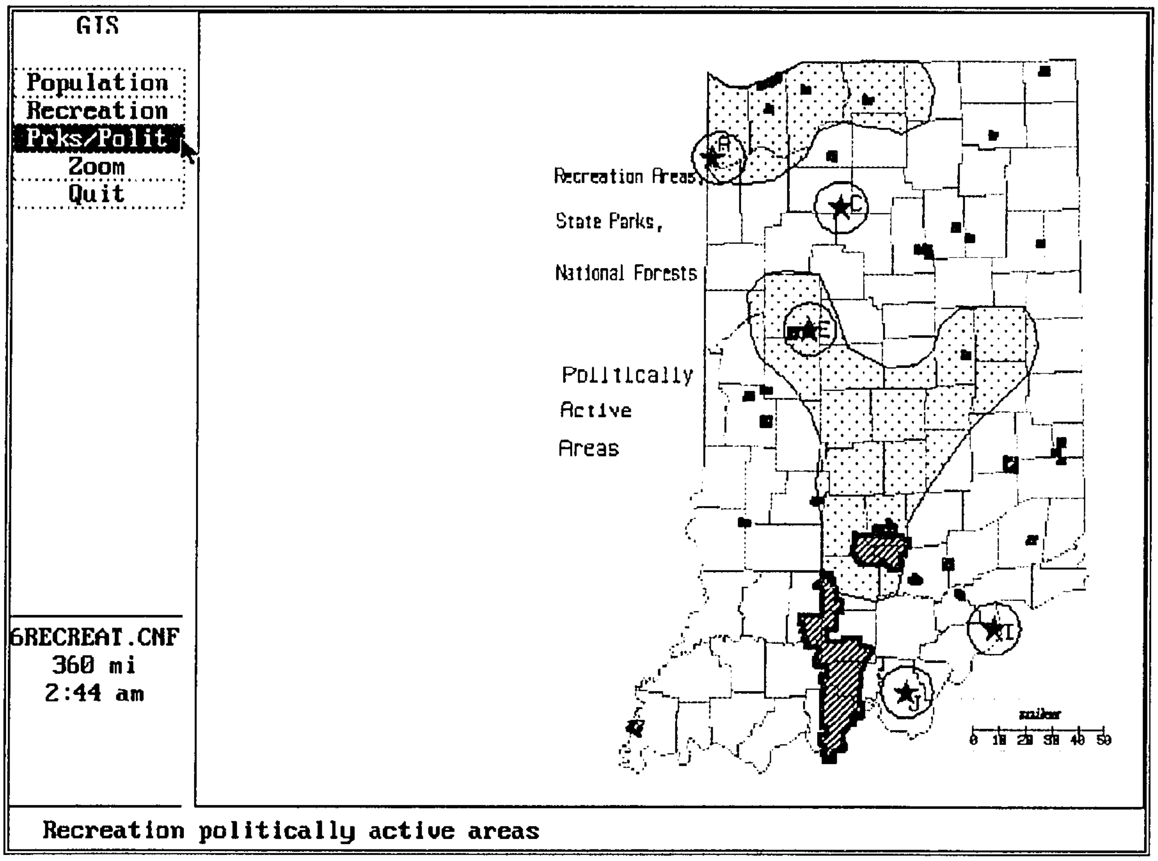
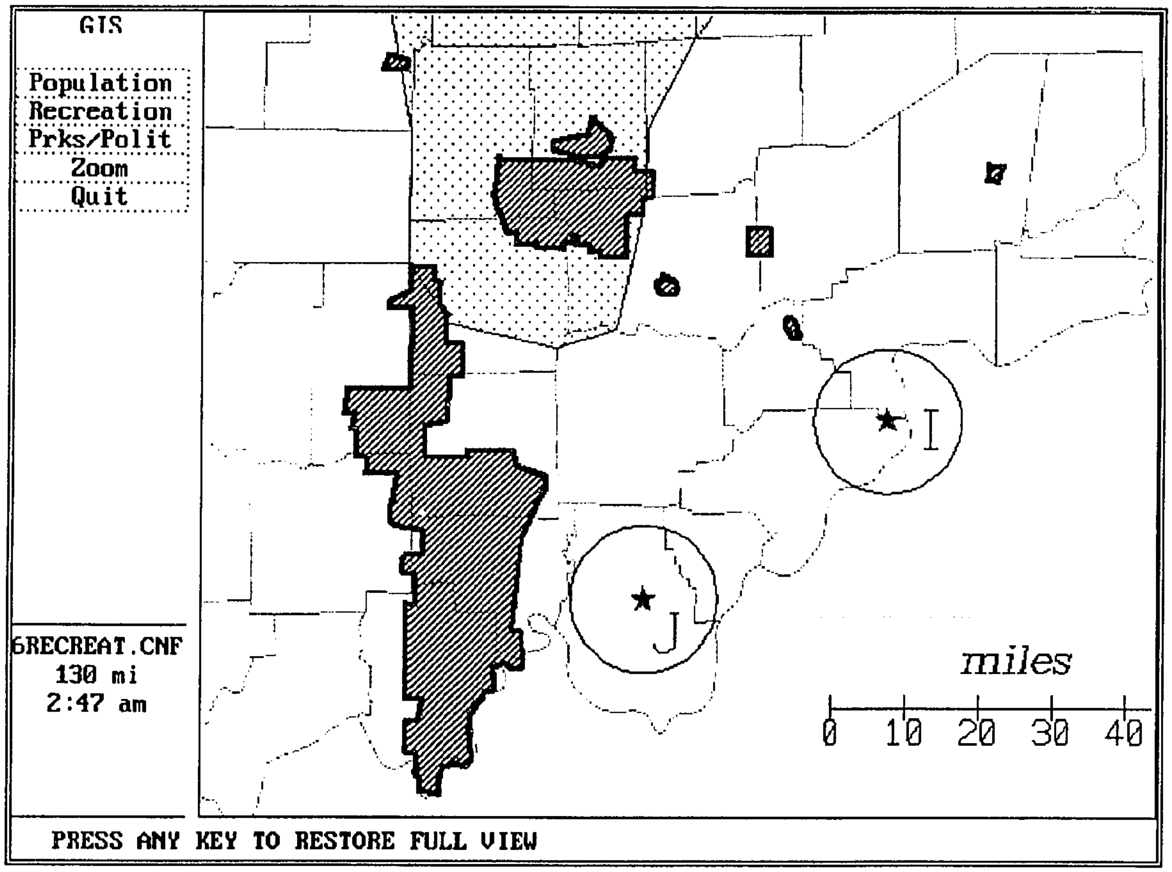


Figure A6-4
Less Complex Problem, Example of Zoom function



Appendix 7: GIS screens, more complex problem

Figure A7-1
More Complex Problem, Population Criterion Screen

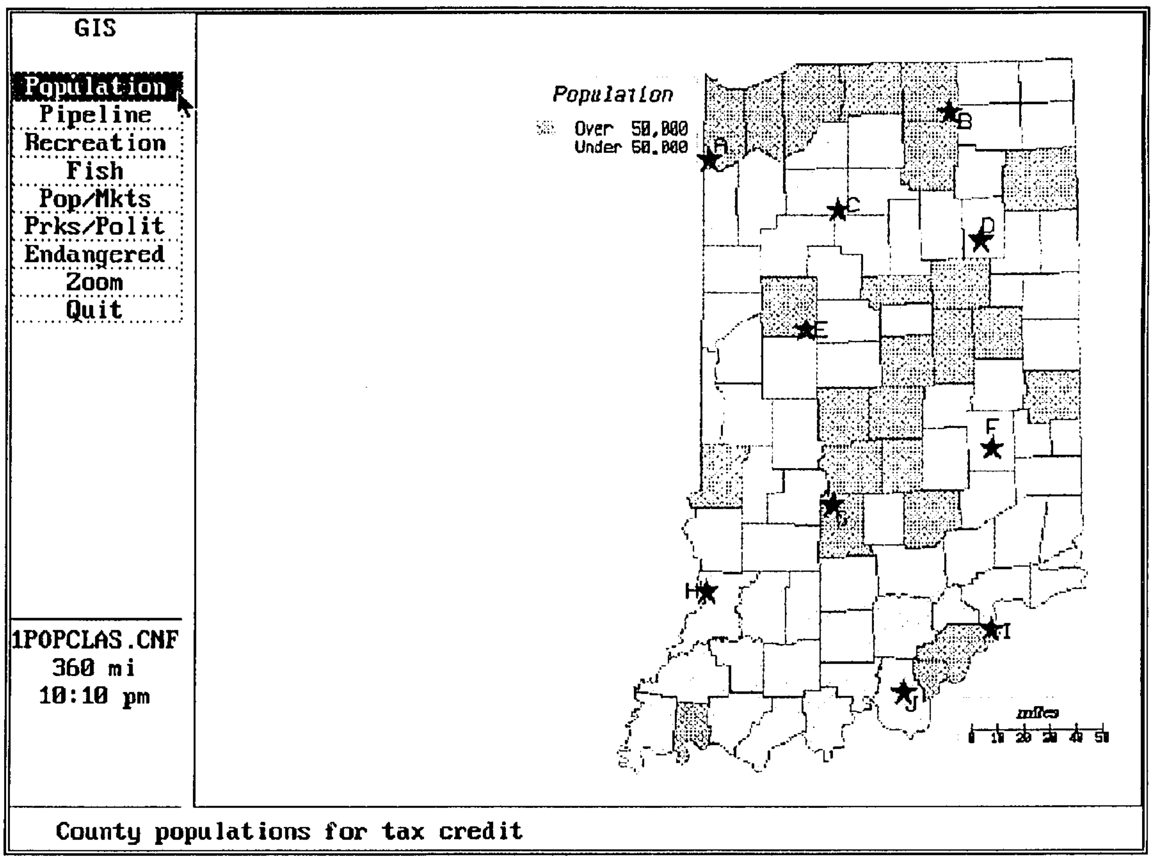


Figure A7-2
More Complex Problem, Pipelines Criterion Screen

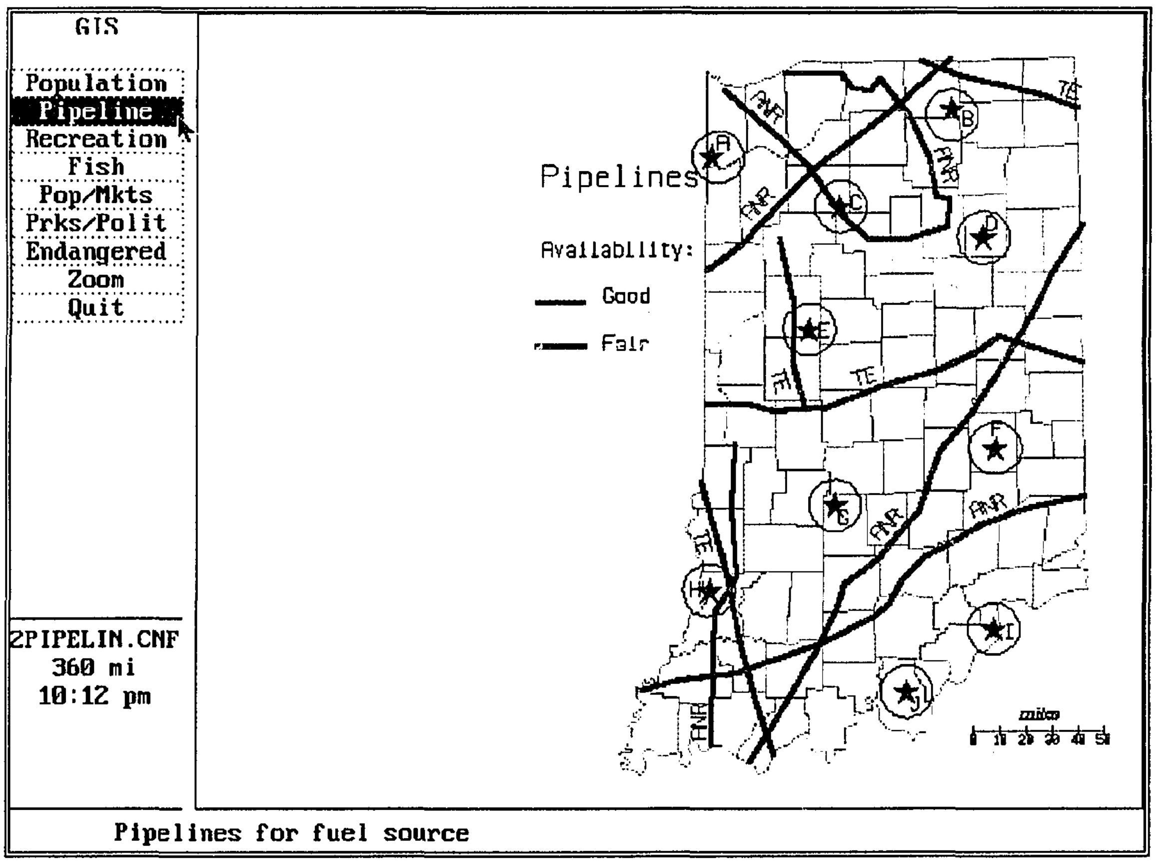


Figure A7-3
More Complex Problem, Recreation Areas Criterion Screen

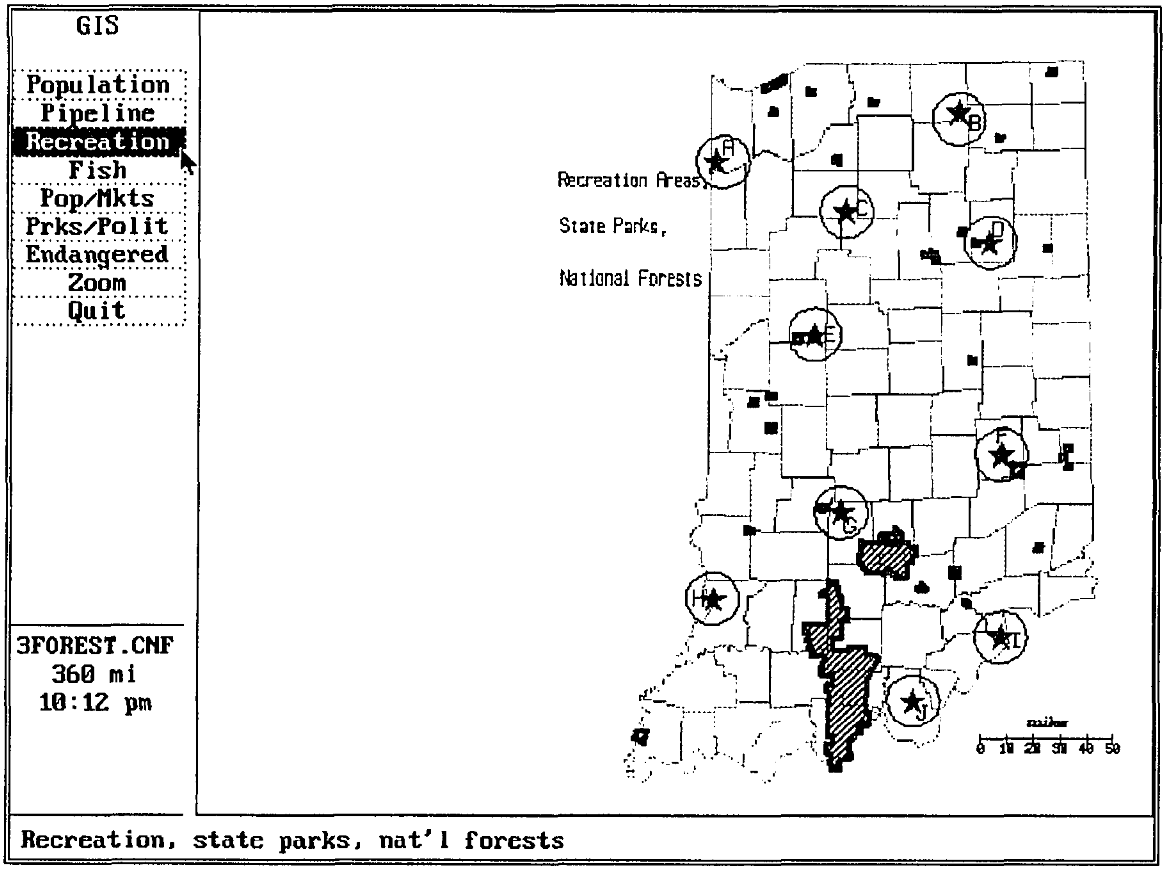


Figure A7-4
More Complex Problem, Endangered Darter Fish Criterion Screen

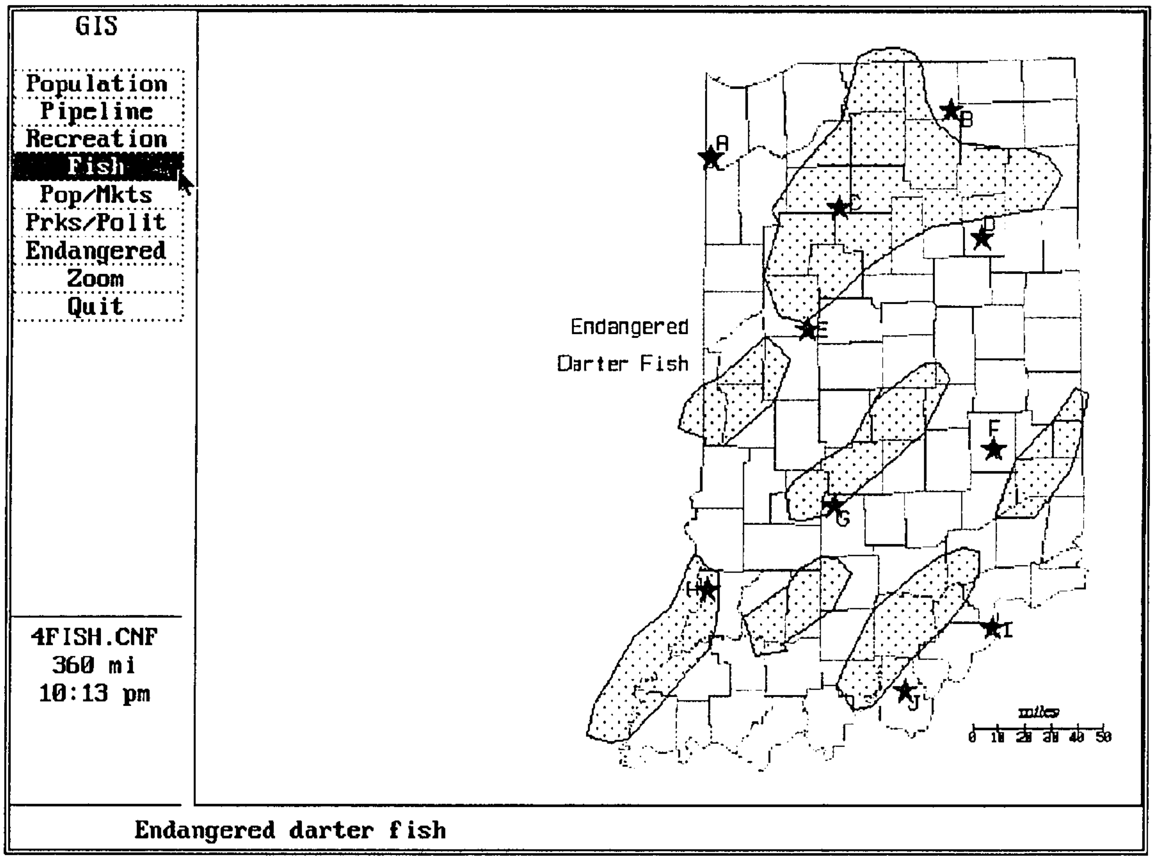


Figure A7-5
More Complex Problem, Population/Major Markets Criterion Screen

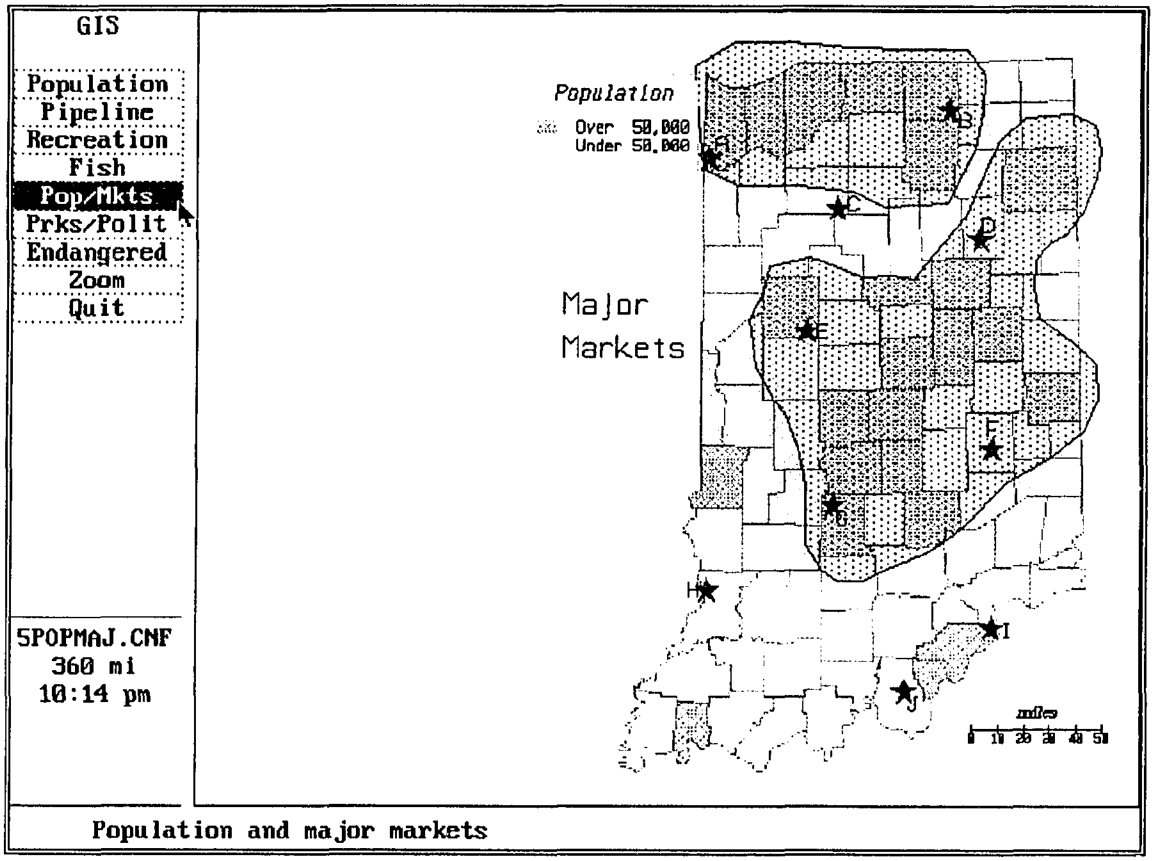


Figure A7-6
More Complex Problem, Rec Areas/Politically Active Areas Criterion Screen

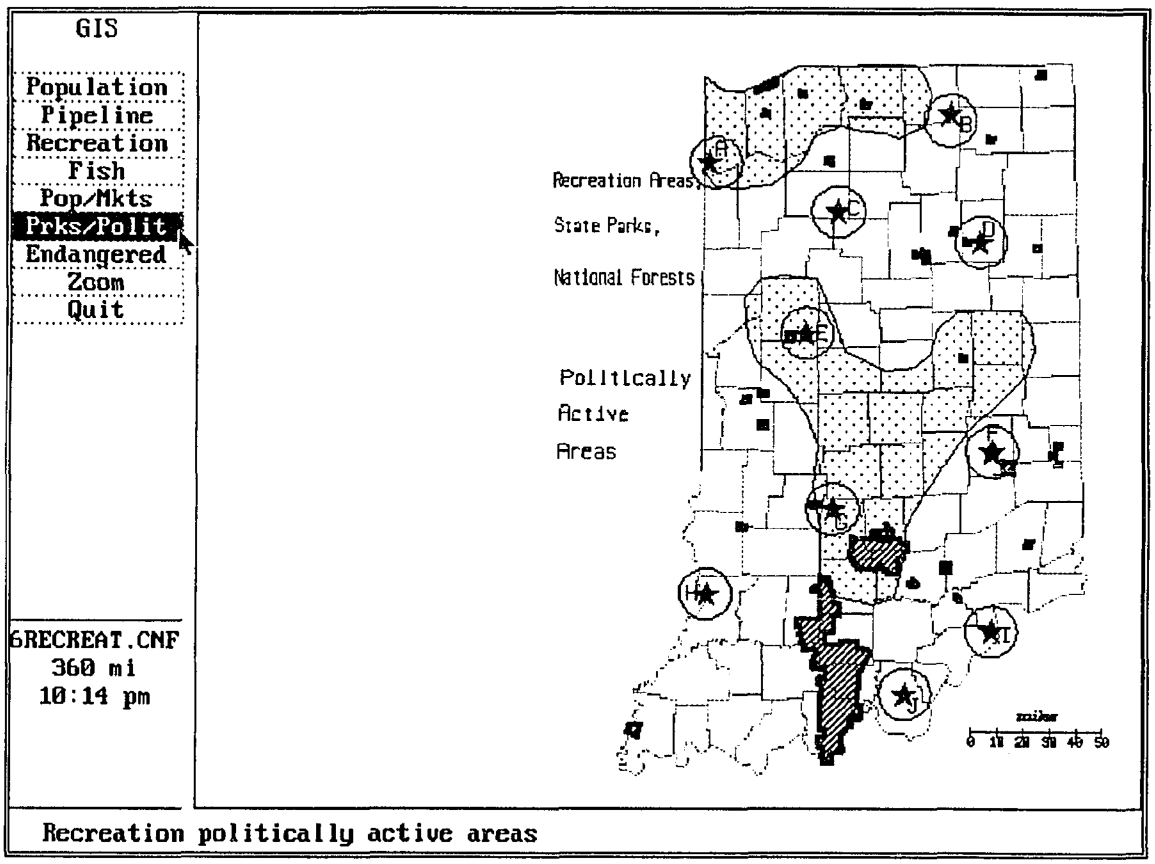
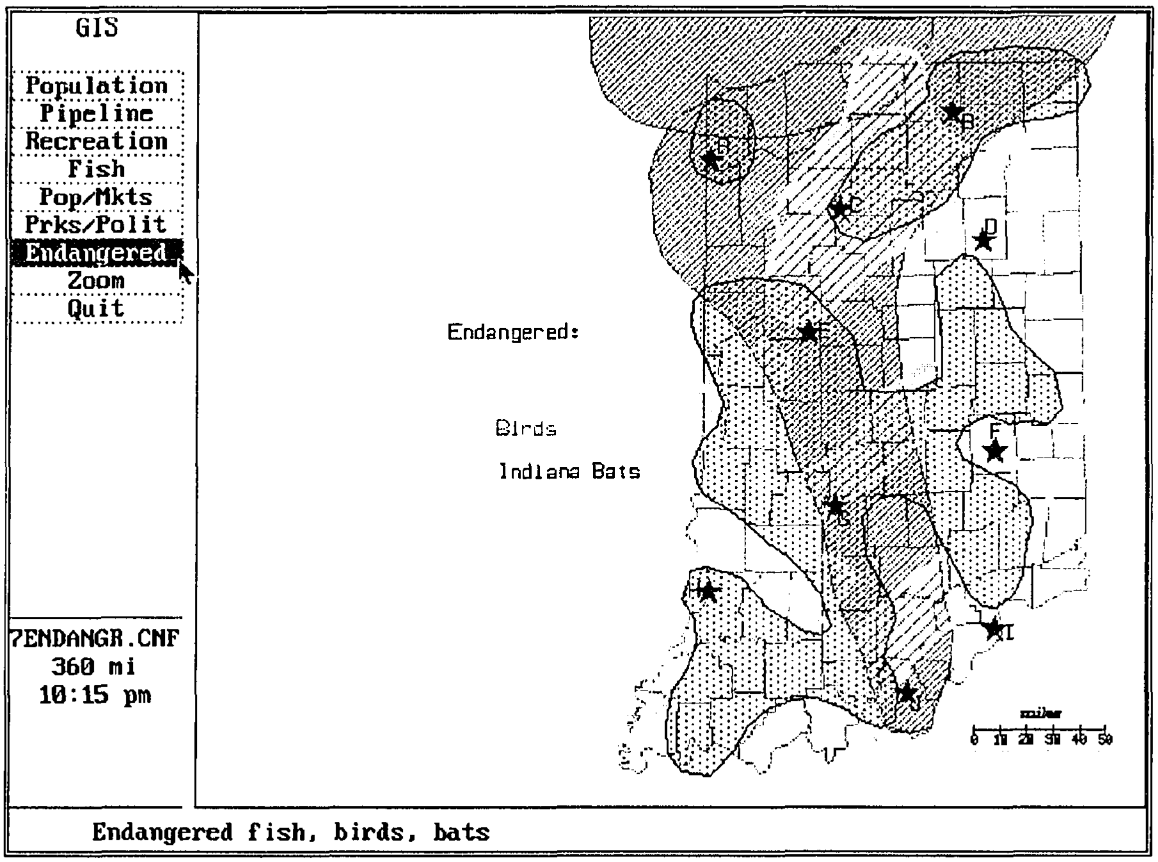


Figure A7-7
More Complex Problem, Flying Endangered Species Criterion



Appendix 8: Post-task questionnaire, no GIS

Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
1	2	3	4	5	6

1 I believe my answer was close to the correct one.
2 I believe my answer was not close to the correct one.
3 My answer was probably more correct than those of most of the other people in the group.
4 Most of the people in the group probably have a more correct answer than mine.
5 I'd get the correct answer on another problem like this one.
6 I wouldn't do very well on another problem like this one.
7 I'd do better if I worked this problem again.
8 If I had to do the problem over again I would not get a more correct answer.
9 I did the best job I could on this problem.
10 I did not work very hard on this problem.
11 I wanted to win the money.
12 The thought of winning the money did not affect how I worked on this problem.
13 I worked hard on this problem because that's the way I normally do things.
14 I didn't work hard on this problem because I don't care if I got the correct answer or not.
15 I had enough time to work on the problem.
16 There was too much information for me to handle in the time available.
17 The written materials were readable and understandable.
18 I had trouble organizing and using the written materials.
19 I understood what I was supposed to do.
20 The instructions were confusing.
21 This was a interesting problem to work on.
22 This problem was boring.
23 Getting my answer was easy.
24 This was a difficult problem to work on.
39 I enjoy using computers.
40 I don't like computers.
41 I like finding out new ways I can use computers.
42 I'll only use a computer when I have to.
43 We should always be looking for more ways to use computers.
44 The world would be better off without so many computers.
45 Computers are useful tools.
46 Computer don't do much for us except cause problems.

Appendix 9: Post-task questionnaire, with GIS

Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree
1	2	3	4	5	6

1 I believe my answer was very close to the correct one.
2 believe my answer was not close to the correct one.
3 My answer was probably more correct than those of most of the other people in the group.
4 Most of the people in the group probably have a more correct answer than mine.
5 I'd get the correct answer on another problem like this one.
6 I wouldn't do very well on another problem like this one.
7 I'd do better if I worked this problem again.
8 If I had to do the problem over again I would not get a more correct answer.
9 I did the best job I could on this problem.
10 I did not work very hard on this problem.
11 I wanted to win the money.
12 The thought of winning the money did not affect how I worked on this problem.
13 I worked hard on this problem because that's the way I normally do things.
14 I didn't work hard on this problem because I don't care if I got the correct answer or not.
15 I had enough time to work on the problem.
16 There was too much information for me to handle in the time available.
17 The written materials were readable and understandable.
18 I had trouble organizing and using the written materials.
19 I understood what I was supposed to do.
20 The instructions for this problem were confusing.
21 This was an interesting problem to work on.
22 This problem was boring.
23 Getting my answer was easy.
24 This was a difficult problem to work on.
39 I enjoy using computers.
40 I don't like computers.
41 I like finding out new ways I can use computers.
42 I'll only use a computer when I have to.
43 We should always be looking for more ways to use computers.
44 The world would be better off without so many computers.
45 Computers are useful tools.
46 Computers don't really do much except cause problems.

25 I learned quickly enough how to get the maps I needed on the computer.
26 I never understood how to get the right maps I needed on the computer.
27 The computer maps were readable.
28 I had trouble reading the maps on the computer.
29 I understood the information on the computer maps.
30 The maps on the computer were confusing.
31 The computer maps had easier-to-get information than the paper maps.
32 I found the paper maps to have easier-to-get information.
33 I used the paper maps instead of the computer maps.
34 I didn't use the paper maps at all.
35 I used the computer maps more than the paper maps.
36 I used the paper maps more than the computer displays.
37 I used the computer maps instead of the paper maps.
38 I didn't use the paper maps.

Appendix 10: Script for experiment session -- no GIS

Welcome to our experiment, and thank you for coming. My name is Marty Crossland, and I am the researcher conducting this experiment. Your participation will help us understand better how people approach and solve certain types of problems related to locations and geography.

Personal Characteristics Questionnaire

First of all, please make sure that you have completed the questionnaire mailed to you with your confirmation. If you haven't, please take a few minutes now to complete it.

Label on PCQ

Keep the labels I sent to you handy throughout your time here this morning. I'll be asking you to label various items at different times. Right now, please put one of the labels in the upper right-hand corner of your completed questionnaire.

SIGN-IN/QUESTIONNAIRE

Now we're ready to proceed. We'll be going back and forth from the written materials to the computer, so please bear with us.

First, please look at your computer screen. It has a menu with five items on it. We will be working in order down all five items. When selecting an item from this menu, please type the number key only. DO NOT PRESS ENTER AFTER YOU TYPE A NUMBER. This will avoid typing ahead of the machine and into trouble.

SIGN-IN

Now select item 1 by just tapping once on the 1-key. In a short while you will see a screen with some information and a box for you to make an entry. Please follow this rule for the whole sessions. Anytime there is information on the screen, READ IT! Even though there may be a prompt at the bottom inviting you to "press any key to continue" YOU NEED TO READ EACH SCREEN BEFORE DOING SO! If you fail to read one you may miss some important instructions or lose the flow of the process temporarily. Do read the screens.

Now please look on your labels I sent you and find your participant ID number (3 digits). When you find it please enter it in the box on the sign-in screen. Press Enter to continue.

NFC Questionnaire

READ THE SCREENS! Keep moving forward until you have the first screen of a questionnaire. We'd like to learn a little bit about how you approach problem-solving. Please answer this questionnaire as truthfully as you can, remembering that the results are completely anonymous. We'd like you to give us your level of agreement with each statement, as if you'd just spoken it to yourself. Please answer as you think you REALLY ARE, rather than how you think you should be or how you'd like to be. Take a few minutes now and answer each question by typing the number (1 thru 9) that best describes where your view falls on the agreement scale. Press Enter after each one, and remember that you cannot return to a question once you've left it.

GEFT

Now we'd like to look at another facet of how you solve problems. I'm going to give you a short, timed test. Please read the first three pages of instructions, but do not look ahead any further in the test booklet or begin working on it until I tell you.

Label test

First please place one of your labels in the upper right corner of the test booklet. Do not fill out the information on the front cover. When you have the label in place, please read the directions on the first three pages. Please STOP at the point where you are asked to. (pause for their reading)

We will be doing this test in three segments. The first will be for two minutes. Please keep in mind that:

1. You should completely erase all mistakes
2. Don't skip a problem unless you're hopelessly stuck
3. Trace only ONE simple form on each problem.
4. Form is always same size, proportions, and orientation.

You will have 2 minutes to complete pages 5 thru 11. Please stop where indicated at the bottom of page 11. Ready, begin! (2 min).

You'll now have 5 minutes to complete pages 11-21. Please stop where indicated at the bottom of page 21. If you finish before time is up, do not turn back to section 1 to work on any of those problems. Ready, begin (5 min).

Now you'll have 5 more minutes for the last section. Please work the rest of the problems in the book. If you finish before time is up, do not turn back to either of the other sections for more work on them. You may only work on section 3. Ready, begin (5 min).

Now please insert the test booklet in your envelope.

PRACTICE PROBLEM

We're ready now to work a practice problem similar to the main one you'll be working in a few minutes. The purpose of this practice is to familiarize you with the organization of the materials you'll use, the computer screens, and the type of problem we're addressing.

Overview

Please look at the screen for item number 2 -- practice problem. Please now tap the number 2 key to start it up on your computer.

Now please remove the paper-clipped group of papers from your envelope which have a green cover sheet labeled "Practice Problem." Do not remove the other group with the blue cover -- please leave it in the envelope. Please read the problem statement now, and look through the attached maps for reference.

<u>Assign points</u>

The first order of business is to assign points to the two sites under consideration on both of the criteria.

<u>Rank the sites</u>

We then want to develop a priority ranking of the sites based on the points totals. The site with the most points will be ranked number 1, and the second will be ranked number 2.

Paper maps

You should now look at the maps in the package. First consider the Roads criterion map. Note that site A is not within 2 miles of a road (use the scale on the map for reference) so it will get zero points for roads. At the bottom of the green sheet in the table labeled roads, enter a Zero for site A. Site B on the other hand, IS within 2 miles of a road. Therefore, we will give it 4 points for the Roads criterion. Enter 4 in the box for Site B in the Roads table.

<u>Selecting maps</u>

Now we'd like to look at the next criterion. Please locate the Environmentally Sensitive Areas map. Now we'll look at the Environmental criterion. A site will get 3 points if it is outside the environmentally sensitive area. Note that both sites meet this condition, so they both receive 3 points in the Environmental Area table. Please enter that now in the scoring table on the green sheet.

Entering the answers

Now select item 4 from the main menu on your screen. While the program is coming up take a minute to total the points for each site and fill out the RANK in the last table of the scoring sheet. Do not enter point totals! Enter the Rank number you have determined (highest points gets priority 1, etc.)

READ THE SCREENS! Now simply copy the points from your scoring sheet into the corresponding tables which appear one-by-one on your screen. As you finish a table you be asked if you are indeed finished. Answer Y if you are, N if you're not. You don't need to press Enter after any of the responses on these screens. READ ANY INSTRUCTION AND INFORMATION SCREENS WHEN THEY COME AND FOLLOW THEM.

On the main problem, after you've entered the Ranks you will get one additional question whether you are completely finished entering your answers. If you had an error earlier in the data input answer N and you can quickly cycle through your answers by repeatedly pressing the Enter key until you get to the one you need to change. Make your correction, followed by additional Enters (and Y's to the questions about if finished) to get back to the exit point. Answer 'Y' that you are finished entering answers. Now the screen will return to the main menu.

Any questions about the operation or procedures?

MAIN PROBLEM

Now you're about to work the main problem. It will be very similar to the practice problem you just worked.

Overview

You will have a similar locational problem with more sites. You will have to weigh several sites against several criteria.

Assign points

Assign points to each site based on each criterion and write them on the yellow scoring sheet.

Rank the sites

After you have considered all the criteria for all the sites, determine the ranking of each site, remembering that the site with the highest total points will be ranked number 1.

Accuracy and Timing Issues

There are three cash prizes for first, second and third place. You will be graded first and foremost on accuracy. The lowest number of errors will win the contest. If there is a tie for correctness, then the tie will be decided by the shortest elapsed time you used to solve the problem. These totals will be automatically reported for you (see item 5 on the main menu).

Starting/Stopping the clock

A couple of important notes about starting and stopping the clock. Note on the main menu item number 3. We will all select number 3 together to start our respective clocks. This will also call up the computer maps you need to work the problem. Once you have completed your analysis and have exited from the map display program as we did in the practice problem you will be returned to the main menu. You will then need to immediately select number 4 to record your answers. As soon as you finish recording your answers the clock timer on your problem will automatically stop.

READ THE SCREENS. You will then go directly to a short questionnaire about the problem you just worked. Please go ahead and answer it with your reactions to the statements posed.

Videotape

To help lend a bit of reality to the problem you're about to work, please watch this short videotape of a news feature which was recently broadcast on CNN. The technology discussed in the feature is the same as the one you will be considering in the problem.

Work the problem/questionnaire

Now please select menu item 3 by tapping the numeric 3 key. Your time clock has now started. Immediately remove the blue "main problem" package from your envelope and begin working on it. For your reference, pull out the yellow scoring sheet on the back of the package. It has scoring guidelines you will probably want to use after you have read the full problem from the blue page. Also, there is tracing paper in the package should you want to use it on the maps.

[As they finish up recording answers] Go ahead and move into the final questionnaire when you finish entering your answers.

WRAP-UP

I'd like to take a few moments now to label some things.

Label score sheets

Please place one of your labels in the upper right corner of your yellow answer sheet.

Label Envelope

Now please place one label in this (indicate!) corner of your envelope.

SCORING AND PRIZES

Now please select number 5 from the main menu. When asked enter the following password: "112753". Who has the lowest score? "Fastest time?"

Label Disk

One last item. Please remove the disk from your computer and place your last label in the upper right corner. Don't cover the notch in the disk.

Thanks again for your participation. You've made a valuable contribution to our study!

Appendix 11: Script for experiment session -- with GIS

Welcome to our experiment, and thank you for coming. My name is Marty Crossland, and I am the researcher conducting this experiment. Your participation will help us understand better how people approach and solve certain types of problems related to locations and geography.

Personal Characteristics Questionnaire

First of all, please make sure that you have completed the questionnaire mailed to you with your confirmation. If you haven't, please take a few minutes now to complete it.

Label on PCQ

Keep the labels I sent to you handy throughout your time here this morning. I'll be asking you to label various items at different times. Right now, please put one of the labels in the upper right-hand corner of your completed questionnaire.

SIGN-IN/QUESTIONNAIRE

Now we're ready to proceed. We'll be going back and forth from the written materials to the computer, so please bear with us.

First, please look at your computer screen. It has a menu with five items on it. We will be working in order down all five items. When selecting an item from this menu, please type the number key only. DO NOT PRESS ENTER AFTER YOU TYPE A NUMBER. This will avoid typing ahead of the machine and into trouble.

SIGN-IN

Now select item 1 by just tapping once on the 1-key. In a short while you will see a screen with some information and a box for you to make an entry. Please follow this rule for the whole sessions. Anytime there is information on the screen, READ IT! Even though there may be a prompt at the bottom inviting you to "press any key to continue" YOU NEED TO READ EACH SCREEN BEFORE DOING SO! If you fail to read one you may miss some important instructions or lose the flow of the process temporarily. Do read the screens.

Now please look on your labels I sent you and find your participant ID number (3 digits). When you find it please enter it in the box on the sign-in screen. Press Enter to continue.

NFC Questionnaire

READ THE SCREENS! Keep moving forward until you have the first screen of a questionnaire. We'd like to learn a little bit about how you approach problem-solving. Please answer this questionnaire as truthfully as you can, remembering that the results are completely anonymous. We'd like you to give us your level of agreement with each statement, as if you'd just spoken it to yourself. Please answer as you think you REALLY ARE, rather than how you think you should be or how you'd like to be. Take a few minutes now and answer each question by typing the number (1 thru 9) that best describes where your view falls on the agreement scale. Press Enter after each one, and remember that you cannot return to a question once you've left it.

GEFT

Now we'd like to look at another facet of how you solve problems. I'm going to give you a short, timed test.

Label test

First please place one of your labels in the upper right corner of the test booklet. Do not fill out the information on the front cover. When you have the label in place, please read the directions on the first three pages. Please STOP at the point where you are asked to. (pause for their reading)

We will be doing this test in three segments. The first will be for two minutes. Please keep in mind that:

1. You should completely erase all mistakes
2. Don't skip a problem unless you're hopelessly stuck
3. Trace only ONE simple form on each problem.
4. Form is always same size, proportions, and orientation.

You will have 2 minutes to complete pages 5 thru 11. Please stop where indicated at the bottom of page 11. Ready, begin! (2 min).

You'll now have 5 minutes to complete pages 11-21. Please stop where indicated at the bottom of page 21. If you finish before time is up, do not turn back to section 1 to work on any of those problems. Ready, begin (5 min).

Now you'll have 5 more minutes for the last section. Please work the rest of the problems in the book. If you finish before time is up, do not turn back to either of the other sections for more work on them. You may only work on section 3. Ready, begin (5 min).

Now please insert the test booklet in your envelope.

PRACTICE PROBLEM

We're ready now to work a practice problem similar to the main one you'll be working in a few minutes. The purpose of this practice is to familiarize you with the organization of the materials you'll use, the computer screens, and the type of problem we're addressing.

Overview

Please look at the screen for item number 2 -- practice problem. Please now tap the number 2 key to start it up on your computer.

Now please remove the paper-clipped group of papers from your envelope which have a green cover sheet labeled "Practice Problem." Do not remove the other group with the blue cover -- please leave it in the envelope. Please read the problem statement now.

Assign points

The first order of business is to assign points to the two sites under consideration on both of the criteria.

Rank the sites

We then want to develop a priority ranking of the sites based on the points totals. The site with the most points will be ranked number 1, and the second will be ranked number 2.

Electronic map

Startup Application

You should now see a map on your computer screen. Before we do anything else, you need to call up a simple menu. YOU'LL NEED TO DO THIS ON THE MAIN PROBLEM, SO PLEASE TAKE NOTE. When the computer is through drawing, just press the A key once, followed by the Enter key. That's it. You'll only have to do this one time after you start the main problem, BUT YOU MUST DO IT!

First consider the Roads criterion now on your screen. Note that site A is not within 2 miles of a road (the circles around the sites are 2 miles in radius for your easy reference), so it will get zero points for roads. At the bottom of the sheet in the table labeled roads, enter a Zero for site A. Site B on the other hand, IS within 2 miles of a road. Therefore, we will give it 4 points for the Roads criterion. Enter 4 in the box for Site B in the Roads table.

Selecting maps

Now we'd like to look at the next criterion. To see the next map, all you need to do is use your down arrow key to move the pointer in the upper left down to the next map name in the menu. When it is highlighted (Environmental Area) just press Enter. That map will then be displayed. While it is coming up feel free to review the paper materials for the problem.

Now we'll look at the Environmental criterion. A site will get 3 points if it is outside the environmentally sensitive area. Ncte that both sites meet this condition, so they both receive 3 points in the Environmental Area table. Please enter that now in the scoring table.

Zooming

If you weren't sure if site A is outside the area, you can zoom in on it. Do that now by pressing the down arrow once to highlight zoom, then press Enter. A pair of cross-hairs will appear on the map. Use the arrow keys to move the center of the crosshairs to as near to site A as you can. Then press Enter. The map around site A will now be enlarged for closer study. When you are finished looking at it, look at the bottom of the screen for the message telling you to press any key to restore the full map. Press the spacebar or the Enter key to restore the map.

Quitting

Now that we're finished assigning points on both maps we can use the down arrow key to highlight Quit and press Enter. The menu will disappear but a new longer one will appear in its place. Now just press the Escape key followed by an Enter (to accept the Yes answer to the "Quit MapInfo?" question. This takes you to a screen to enter your answers from the paper score sheet to the computer.

Entering the answers

Take a minute to total the points for each site and fill out the RANK in the last table of the scoring sheet. Do not enter point totals! Enter the Rank number you have determined.

Now simply copy the points from your scoring sheet into the corresponding tables which appear one-by-one on your screen. As you finish a table you be asked if you are indeed finished. Answer Y if you are, N if you're not. You don't need to press Enter after any of the responses on these screens. READ ANY INSTRUCTION AND INFORMATION SCREENS WHEN THEY COME AND FOLLOW THEM.

On the main problem, after you've entered the Ranks you will get one additional question whether you are completely finished entering your answers. If you had an error earlier in the data input answer N and you can quickly cycle through your answers by repeatedly pressing the Enter key until you get to the one you need to change. Make your correction, followed by additional Enters (and Y's to the questions about if finished) to get back to the exit point. Answer 'Y' that you are finished entering answers. Now the screen will return to the main menu.

Any questions about the operation or procedures?

MAIN PROBLEM

Now you're about to work the main problem. It will be very similar to the practice problem you just worked.

Overview

You will have a similar locational problem with more sites. You will have to weigh several sites against several criteria.

Assign points

Assign points to each site based on each criterion and write them on the yellow scoring sheet.

Rank the sites

After you have considered all the criteria for all the sites, determine the ranking of each site, remembering that the site with the highest total points will be ranked number 1.

Accuracy and Timing Issues

There are three cash prizes for first, second, and third place. You will be graded first and foremost on accuracy. A lowest number of errors will win the contest. If there is a tie for correctness, then the tie will be decided by the elapsed time you used to solve the problem. These totals will be automatically reported for you (see item 5 on the main menu).

Starting/Stopping the clock

A couple of important notes about starting and stopping the clock. Note on the main menu item number 3. We will all select number 3 together to start our respective clocks. This will also call up the computer maps you need to work the problem. Once you have completed your analysis and have exited from the map display program as we did in the practice problem you will be returned to the main menu. You will then need to immediately select number 4 to record your answers. As soon as you finish recording your answers the clock timer on your problem will automatically stop.

READ THE SCREENS. You will then go directly to a short questionnaire about the problem you just worked. Please go ahead and answer it with your reactions to the statements posed.

Videotape

To help lend a bit of reality to the problem you're about to work, please watch this short videotape of a news feature which was recently broadcast on CNN. The technology discussed in the feature is the same as the one you will be considering in the problem.

Work the problem/questionnaire

Now please select menu item 3 by tapping the numeric 3 key. Your time clock has now started. Immediately remove the blue "main problem" package from your envelope and begin working on it. For your reference, pull out the yellow scoring sheet on the back of the package. It has scoring guidelines you will probably want to use after you have read the full problem from the blue page. Also, there is tracing paper in the package should you want to use it on the maps.

[as the maps come up on the screen] Please remember to press A, then enter as soon as the map finishes displaying on your screen. This brings up the short menu for the problem. Note that the first map is a county map shaded by population. This map should be sufficient by itself to score the first criterion. Remember to use the up and down arrow keys, followed by Enter, to select subsequent maps for your review.

[As they begin to finish up with the electronic maps] Remember, to exit the map program and record your answers, move the arrow to Quit, press Enter, then at the next long menu press the escape key, followed by Enter to answer yes and quit. Then select item 4 from the main menu to record your answers. READ YOUR SCREENS!

[As they finish up recording answers] Go ahead and move into the final questionnaire when you finish entering your answers.

WRAP-UP

I'd like to take a few moments now to label some things.

Label score sheets

Please place one of your labels in the upper right corner of your yellow answer sheet.

Label Envelope

Now please place one label in this (indicate!) corner of your envelope.

SCORING AND PRIZES

Now please select number 5 from the main menu. When asked enter the following password: "112753". Who has the lowest score? "Fastest time?"

Label Disk

One last item. Please remove the disk from your computer and place your last label in the upper right corner. Don't cover the notch in the disk.

Thanks again for your participation. You've made a valuable contribution to our study!

VITA

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