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An Experimental Examination of Spatial DecisionSupport System Effectiveness: The Roles of Task Complexity and Technology

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Abstract

A laboratory experiment was used to investigate the effects on decision maker performance of using geographic information system (GIS) technology as a spatial decision support system (SDSS). The research examined two independent variables: task complexity (i.e., low, medium, and high complexity, and SDSS use (i.e., no SDSS versus SDSS support). Professionals who are experienced decision makers completed a site location task that required decisions to be made based upon spatially-referenced information. The results confirm the hypotheses and show that SDSS use and task complexity both have an important impact on decision quality and solution time. The study builds upon and extends image theory as a basis for explaining efficiency differences resulting from differing graphical displays of spatial information.

Introduction

In considering the decisions that managers and decision makers typically face, one of the variables that is most commonly taken into account is location. Whether selecting a site for a new facility, assigning personnel to territories, managing the flow of materials and product through the value chain, or simply deciding about which conference room in which to hold the staff meeting, location is a factor in the decision. In fact, as much as 80% of business problems require that spatial data be considered in the decision-making process.

Crossland and colleagues (Crossland, 1992; Crossland, Perkins, & Wynne, 1995; Crossland, Perkins, & Herschel, 1996) showed that, among other things, the addition of GIS technology, in the form of a spatial decision support system (SDSS), to the decision environment for a spatially-referenced task reduced the decision time and increased the decision-making performance of individual decision makers. Their research involved the use of undergraduate and graduate student subjects. Prior research has suggested that significant differences can potentially exist between student subjects and 'real-world' subjects (Gordon, Slade, & Schmitt, 1986; Hughes & Gibson, 1991). The present study expands on Crossland and colleagues' work by largely replicating their study, but using professional decision makers as subjects.

Hypotheses and Methodology

A SDSS may be considered to make a positive contribution to problem solving if it enables the decision maker to reach (a) a more accurate solution, (b) a faster solution to a given problem, or (c) both of these. For this study we postulated that a SDSS will present more efficient graphical displays (as defined in Image Theory by Bertin, 1983) than conventional paper maps, and thus it may be hypothesized that a user of a SDSS will benefit from the greater efficiencies predicted by Image Theory. This suggests the two hypotheses tested in this study:

H1: For the same task, decision makers using the SDSS will solve the problem in less time than those using only paper maps.

H2: For the same task, decision makers using the SDSS will solve the problem with fewer errors than those using only paper maps.

Independent Variables

Two independent variables were used in the study:

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

2. *Presence / absence of SDSS*. 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, in addition to the paper maps and tabular data, subjects were also provided with a SDSS which could be used by subjects to display maps containing case-relevant information.

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 used to evaluate this variable. Subjects were asked to record the time they finished completing the task.

2. *Accuracy*. The solution determined by each subject was recorded on a scoring sheet that was included in the task materials. The problem was objective and had a predetermined and objectively-measurable solution. The nature of the task required the subjects to rank order a series of alternative facility sites based on the various spatial criteria presented in 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 three levels of problem complexity were

being considered, the error score was converted to a percentage of total possible error for comparisons across design cells.

Controlled Variables

Variables which could have an impact on the study and therefore were controlled include: Nature of the task; training; experimental setting; solution scoring rule; subject pool and assignment to design cells.

Research Methodology

The research presented here represents an extension to earlier studies examining SDSS (Crossland, 1992; Crossland et al., 1995, 1996). The present study involved the manipulation of the availability of SDSS, task complexity. The two dependent variables, decision time and accuracy, were measured jointly in accordance with the suggestions of previous researchers (Hoadley, 1990; Jarvenpaa, 1988, 1989). An six-cell, 2x3, factorial design was employed for the study. The unit of analysis was the individual decision maker.

Subjects

The participants consisted of employment security professionals working for state employment security offices in the United States. These individuals were drawn from a population of trainees participating in one of six training sessions that took place during the summer and fall of 1996 and the Spring of 1997. Two of the training sessions focused on the application of GIS technology to economic and labor problems while the remaining four sessions focused on a broader array of topics including economics, data analysis and interpretation, and information technology (including GIS). The employment security professionals were randomly assigned to a treatment condition within the constraints of scheduling. One exception to this is for the high complexity, no-SDSS cell. In this instance, all subjects were derived from the same training session (the 'Michigan session'). This was because the high complexity, no-SDSS version of the task required the longest amount of time to complete. The Michigan session was the only one in which enough surplus time could be scheduled so that participants could complete the exercise without an artificially imposed time constraint. The Michigan session was one of two sessions which had a focus on GIS.

Experimental setting

The GIS software used for the study was Atlas GIS® from Environmental Systems Research Institute (ESRI) of Redlands, California. A workspace was stored on an experimental disk which allowed subjects to load the required data and images in a standardized manner.

Because the experienced decision makers participated in the experiment in association with a professional training program which was held in various locations across the

United States, it was not possible to use the same facility for all groups. Nevertheless, subjects participating in the experiment completed the task in settings that were not drastically different in terms of the professional ambiance, lighting, and seating arrangement. In all cases, the facilities were either training classrooms or computer labs. In some instances, subjects completing the computer version of the task were in the same room with those who did not use a computer. In all cases, the same individual (one of the authors) provided training on the use of the GIS software, read experimental instructions, and supervised data collection.

Experimental Procedure

After a short introduction and training, subjects were administered the experimental task. The task asked subjects to assume the role of a labor market specialist who is helping a company decide which location they should use to implement a new technology. All the criteria included spatial components. The priority ranking was based on a scoring rule which assigned points to sites based on each criterion. Point assignments were strictly objective, in that each site either met the criterion or did not. Points for each site were recorded on a scoring sheet that contained a listing of all of the sites, information about the criteria, and spaces for the entry of points and ranks. The final evaluation of each site involved summing the total points for that site and comparing each site based on these point totals. The subjects recorded the time when they had completed the entry of the final scores.

Results

A total of 78 subjects participated in the study (42.1% female, 57.9% male). The average age of the participants is 40.33 years (SD=9.13). The primary focus of this study is to identify the relationships of the treatment variables -- SDSS usage and problem complexity -- to the two dependent variables -- solution time and accuracy (see Table 1 for the means of the dependent variables).

Tables 2 and 3 show the results of the ANOVAs for solution time and decision quality. Because there were significant main effects of solution time ($F(1,63)=8.560$; $p<0.005$) and accuracy ($F(1,77)= 3.906$; $p=0.052$) for the availability of SDSS, hypotheses H1 and H2 are both supported.

Table 1
Means and Standard Deviation Scores

	Treatment Conditions					
	Low Complexity		Med. Complexity		High Complexity	
Dependent measures	No SDSS	SDSS	No SDSS	SDSS	No SDSS	SDSS
Solution Time (minutes)						
n	7	8	14	14	10	11
Mean	16.3	15.1	35.4	22.2	63.4	50.4
Std Dev.	7.5	4.3	11.4	13.3	10.6	18.0

Decision Quality (percent error)						
n	11	8	16	16	13	14
Mean	4.4	1.0	5.3	2.6	7.4	6.7
Std Dev.	6.1	2.8	6.4	3.0	5.6	3.5

Table 2
Results of ANOVA for Solution Time

SOURCE	df	MS	F	p*
Problem complexity	1	2.304	55.815	.000***
SDSS availability	1	0.353	8.560	.005***
Residual	58	0.041		
Total	63			

*** significant at $p<.01$

Table 3
Results of ANOVA for Decision Quality

SOURCE	df	MS	F	p*
Problem complexity	1	0.012	5.098	.008***
SDSS availability	1	0.009	3.906	.052*
Residual	72	0.002		
Total	77			

*** significant at $p<.01$

* significant at $p<.10_r$

Discussion

This study is a viable extension to the earlier work of Crossland and colleagues (Crossland, 1992; Crossland et al., 1995, 1996). Several of their findings were found to be transferable to the different population of subjects used in this research. In particular, their findings of major effects due to SDSS usage and task complexity are partially corroborated in the present study. However, we did not find a significant interaction of task complexity with SDSS usage. This study found that the addition of SDSS to the decision environment reduced decision time for the two levels of problem complexity used in the study. By examining how two major components of decision-making -- decision time and decision accuracy -- vary with the use of a SDSS, this study contributes to knowledge about the value of SDSS and GIS technologies.

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