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AN EXPERIMENTAL INVESTIGATION OF THE USE OF COMPUTER-BASED GRAPHICS IN DECISION MAKING*

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This paper presents the results of an experiment designed to investigate the impact of computer-based graphics on decision making. The experimental task consisted of selecting quarterly reorder quantities for an importer under condition of uncertain demand. Subjects in the experiment were participants in an executive program for middle and upper level managers. Each subject received information on the cumulative probability distribution of demand and had an opportunity to run up to eight trial simulations with past demand data using his or her order quantities. After completing the trial simulations, the subjects made quarterly ordering decisions for one year in which the quantities demanded were drawn from the demand distribution.

Treatments included the use of a hard copy terminal and five different types of displays on a CRT. The results of the experiment provide limited support for the use of graphics presentation in an information system. Decision or cognitive style also appears to be an important variable influencing the performance of an individual and the reaction to an information system. The implications of the findings for the design of information systems are discussed.

(INFORMATION SYSTEM DESIGN; DECISION SUPPORT; LABORATORY EXPERIMENT)

1. Background

Mason and Mitroff [8] suggested that the mode of presentation is an important variable in research on information systems. The importance of the mode of output is presumed to be great for systems designed to aid decision makers. For decision support systems, the use of the system output is usually voluntary, in contrast with transactions processing systems such as payroll or order entry where an individual has little discretion in using the system. Thus, in systems that involve managers as users, the mode of output presentation is a potentially important determinant of whether or not the system is implemented and used effectively.

There have been several field studies and experiments with systems which provide graphics output to decision makers. (For the purposes of this paper, computer-based graphics refer to a system in which a cathode-ray tube terminal capable of plotting continuous lines is attached to a computer system.) Scott Morton [9] developed a complex system to aid three managers in production planning activities. The problem required a large number of computations and the decision makers involved had different goals. The graphics system had a dramatic effect on the decision-making process. The participants explored more alternatives instead of accepting the first feasible solution to their planning problem. The amount of time, both elapsed and problem solving, was dramatically reduced through the use of the system. The decision

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makers also seemed to learn more about the decision problem and develop a better understanding of the key variable through the use of a system.

Gerrity [4] reported on a graphics system to aid trust investment officers managers portfolios. The system was used heavily by certain decision makers while others did not adopt it. It appeared that the graphics functions were not used as extensively as originally expected (Stabell [12]).

These two studies were conducted in a field setting with a relatively small number of users. Laboratory research makes it possible to manipulate independent variables in a controlled enrivonment and include sufficient subjects to test for statistical significance.

Dickson et al. [3] summarizes a series of nine experiments conducted at the University of Minnesota. The variables in these experiments included characteristics of the information system like the presence of detailed or summarized data, hard copy or cathode ray tube terminal (CRT) output, the presence of goals and use of decision aids among others.

The conclusion of Dickson et al. most relevant for this study were:

1. CRT output can lead to faster decisions and the use of less data.

2. Graphic output may have the same results as that for a CRT and lead to better decision making.

3. Designers need to consider individual differences; the relevant variables differ according to the type of problem and information system.

The most germane Minnesota experiments for the current study were those conducted by Smith, Barkin and Senn.

Smith [11] used a production simulator with a database capability in his experiment. There were no statistically significant differences in treatments, but performance under different treatments was ordered lowest to highest for: (1) reports on a CRT with no database access, (2) a CRT with the ability to construct tabular reports and (3) a CRT with the ability to build graphical reports.

Barkin [1] examined the use of a time-sharing version of the production simulator and related cognitive style to data selection. For one treatment critical decision making information was mixed with information judged noncritical. The amount of data selected varied according to cognitive style. The report with critical information separated was associated with the selection of significantly less data.

Senn [10] examined a different problem setting, a purchasing environment. The subjects received detailed output from a line printer, summarized output from a printer or summarized output from a CRT. There were no differences in decision quality, however the CRT survey group made the faster decisions.

Benbasset and Schroeder [2] found that subjects receiving graphical output and decision aids had the lower cost solution in an inventory management experiment, though the results were not statistically significant. Subjects using graphical output also required the smallest number of reports.

In a study by Lucas and Nielson [7] graphics were found to have a relatively small impact on decisionmakers compared to all the other variables which affected the decision process. This study showed that the group membership and background of decisionmakers were associated with the way information was used and with performance.

Several conclusions may be drawn from this literature. First, the findings from various studies are rather modest. As a referee for this paper suggested "I am afraid that greater understanding in this area will be accomplished through many small studies... rather than by some major break through".[1]

It is important to have the controls provided by a laboratory setting, but it is difficult to include a large number of variables and subject is any one experiment. The laboratory setting also generally restricts the experiment to investigating one problem type. As another referee suggested an important independent variable often omitted in this research is the structure or type of problem being solved. None of the papers surveyed above included problem structure as an independent variable.[2]

2. Hypotheses

The experiment reported on here was designed to test a series of four hypotheses. The independent variable manipulated during the experiment was the type of terminal output; in addition, the decision style of the subject was measured. The dependent variables included performance on a simulated problem, self reports of information usefulness and tests of problem understanding. The hypotheses in the experiment are:

1. Groups using the CRT will have higher scores than groups receiving hardcopy tabular output for performance, usefulness of information and tests of understanding.

In general prior studies have found that the CRT is superior as an output mode to hard copy reports. A CRT is quiet and usually faster than hard copy terminals: it also appears more modern and less like a typewriter.

2. Groups receiving graphical output on the CRT will have higher scores than nongraphical treatments on the CRT for performance, usefulness of information and tests of understanding.

Based on the work of Scott Morton (1971) graphics should contribute to better solutions. The Lucas and Nielsen study had disappointing results for graphics; however, their findings did suggest that possibly graphics will help in problem understanding. One of the purposes of this experiment is to provide a controlled environment so that differences due to graphics can be explored.

3. Graphics subjects receiving both graphical and tabular output will have higher scores than graphics groups receiving only graphical output for performance, usefulness of information and tests of understanding.

The Lucas and Nielsen [7] study replaced a tabular report with graphics output. Observations during their experiments suggested that the graphics were difficult to read precisely and that both tabular and graphics information would facilitate decision making.

4. Heuristic decisionmakers will have higher scores for graphical treatments and analytic decisionmakers will have higher scores for tabular treatments on the CRTs.

Mason and Mitroff [8] include cognitive or decision style as an important consideration in information systems research and several past field studies have examined this variable (Lucas [6]). Some of the Minnesota experiments included decision style; for example, Chervaney and Dickson compared quantitatively versus verbally oriented subjects (1977). They found that the quantitative aptitude of the subject was associated with performance. Barkin found that the amount of information selected in an experiment varied according to cognitive style (Dickson, et al. [3]).

[1] The author is indebted to the referees for their observations.
[2] The author is indebted to the referees for this observation.

One expects the use and appeal of output to be influenced by the user's cognitive style. Heuristic decisionmakers are characterized by their tendency to look at entire problems while analytics focus more on details. It is expected that graphics will contribute the most to heuristic subjects since a graph or chart presents an overall picture of the data.

3. The Experimental Situation

A simulation exercise was constructed for the experiment. The firm in the simulation imports whisky to the U.S. To simplify the problem, the company has to place a yearly order in December for four deliveries which are made at the beginning of each quarter. Due to the long lead times and limited production capacities the maximum order for a quarter is 25,000 cases.

There are costs for lost customers of $6 per case and the inventory holding cost is 12%. There has been no trend in demand and average sales are 84,000 cases per year. Quarterly demand varies substantially year to year due to short run market conditions.

In order to solve the problem of how many cases to order in December for each of the following four quarters, the subjects had the following data available on the computer.

1. A display of the last five years of demand by quarter.
2. A display of frequency and cumulative relative frequency of demand by quarter for the last ten years.
3. A simulation capability allowing ordering decisions to be tested using the last five years of data (subjects were able to exercise this option up to eight times during the experiment).
4. The ability to test the final ordering decision on data for the following year drawn from the same distribution as the historical data (data were drawn ten times and the results averaged).

The simulator ran on a Hewlett Packard 2000 computer which could be accessed by four Tektronics storage tube graphics CRT's operating at 120 characters per second and a large number of nonimpact, Texas Instruments, hard copy terminals operating at 30 characters per second. The CRT's were located in a small room partitioned off from the main terminal room with dim lighting to facilitate viewing. A single hard copy device was attached to the four CRT's and participants could obtain hard copies of any display. The hard copy terminals, in contrast, were located in a large room with generous working space available. The interface with the simulation required minimal input and typing skills; only single letter yes and no answers and input of the order quantities for four quarters were required.

The subjects in the experiment were executives in a 1974 Stanford University Graduate School of Business summer executive program and all held middle to upper level management jobs. The subjects received a copy of the case and were randomly assigned to a treatment group. Each session lasted one hour on the terminals and following the terminal sessions, a players complete a questionnaire and test.

4. The Experimental Design

The following treatments were used in the experiment:

1. Tabular output of data on a hard copy terminal ($n = 22$);
2. Tabular output on a CRT ($n = 22$);
3. Graphical output only of the probability distribution ($n = 19$);

4. Graphical and tabular output of the probability distribution (see Figure 1) ($n = 19$);

5. Graphical output of simulation costs data (see Figure 2) ($n = 16$);

6. Graphical and tabular simulation of cost data ($n = 21$).

The variables in the study were derived from three sources. A monitor in the simulator recorded performance while an objective test measured understanding of inventory theory and probability distributions. Participants completed a questionnaire which provided data on the usefulness of the various types of output, on satisfaction with the exercise, and on decision style.

The "best simulation" variable is the lowest cost of the eight simulation runs using the five years of historical data. The "next year simulation" variable is the average of running data from the same distribution ten times for one year in the future using the subject's final order quantities. Note that a low numerical value for these dependent variables indicates lower cost which is better performance.

The inventory test and probability test were short examinations in which the subject filled in a blank or circled a response. A question from the inventory test would be: "What is the minimum number of cases to order in quarter 3?" The probability test contained questions like "What is the probability that demand is greater than 100,000 cases (given a particular distribution)?" The samples given on the test corresponded to the treatments, for example, graphics only subjects on probability output received a graph of the probability distributions, but no table of data.

The questionnaire furnished variables on the usefulness of different displays, the probability frequency distribution of demand data and the simulation output. These variables are the average of highly correlated individual questionnaire items such as

QUARTER 4 TO CONTINUE TYPE Y?

DEMAND	CUM REL FREQ
20001 TO 22000	0.00
22001 TO 24000	0.00
24001 TO 26000	0.10
26001 TO 28000	0.40
28001 TO 30000	0.40
30001 TO 32000	0.60
32001 TO 34000	0.80
34001 TO 36000	0.90
36001 TO 38000	1.00

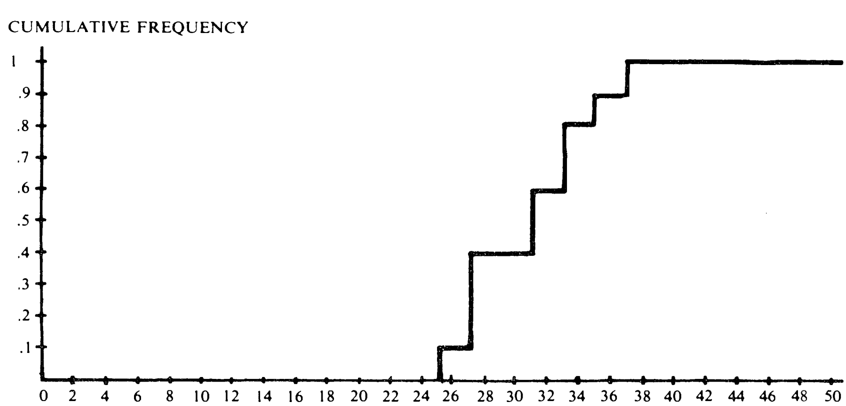

FIGURE 1. Graphical Probability Output.

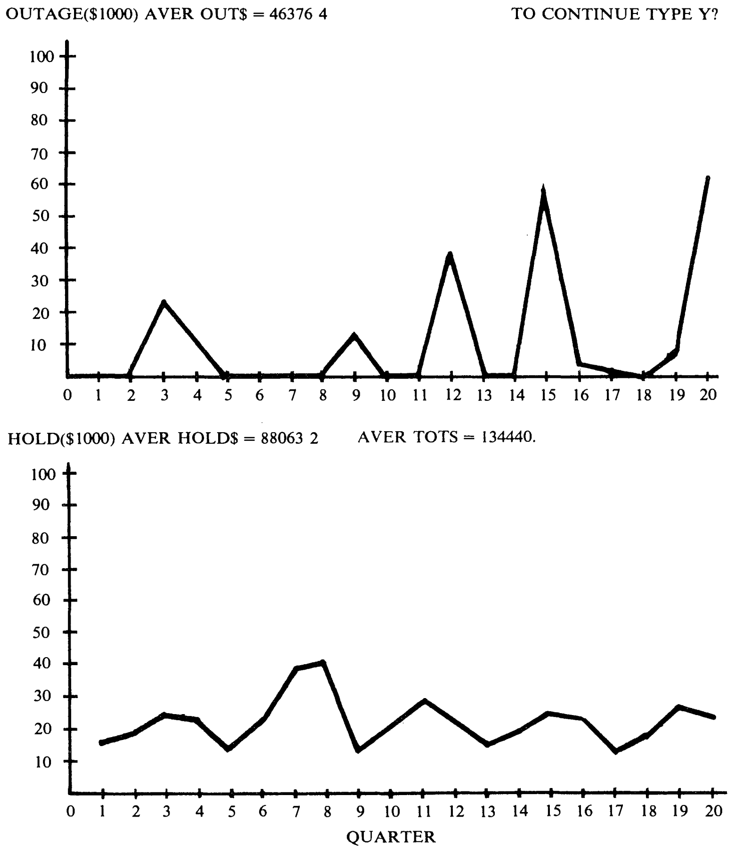

FIGURE 2. Graphical Simulation Output.

the usefulness of the simulation output to develop an understanding of the problem and to develop order quantities.

Included in the variables derived from the questionnaire are a rating of frequency distributions, demand data output and output from the results of the simulation.

The "enjoyment" score came from a single item on the questionnaire, while "satisfaction" is measured as an average of two variables: the subject's confidence in his or her decisions and satisfaction with performance.

The analytic/heuristic variable was measured using a test developed by Barkin[3] which classifies an individual according to his or her predominant approach to problem solving. An analytic decisionmaker is defined as one who would be more inclined to work with data while a heuristic decisionmaker tends to examine the entire problem.

5. Experimental Results

CRT Versus Hard Copy Terminal

Hypothesis 1 predicts that groups using the CRT will score higher than groups receiving output on the hard copy terminals. Table 1 contains the data related to this

[3] Personal correspondence; see also Barkin [1].

TABLE 1

Tabular on Hardcopy Terminal vs CRTs

	Means		
	Tabular hard copy (22)[1]	CRT Tabular (22)	t
Best Simulation[2]	131,788	134,912	1.71**
Next year Simulation	122,771	130,231	1.32*
Frequency distribution output	3.41	4.30	1.59*
Simulation output	5.68	6.36	1.63*
Inventory Test	75.00	56.82	2.67***

	Means		
	Tabular hard copy (22)	Others (97)	t
Best Simulation[2]	131,788	133,297	2.08**
Next year Simulation[2]	127,771	129,894	1.99**
Frequency distribution output	3.41	4.40	2.17**
Demand output	5.33	4.95	1.71**
Inventory Test	75.00	67.53	1.36**

* $p \leqslant 0.10$
** $p \leqslant 0.05$
*** $p \leqslant 0.01$
[1] Number of subjects
[2] Lower scores more favorable

hypothesis. In the top part of the table it can be seen that the group using a hard copy terminal performed significantly better than the group using the CRT without graphical output. However, the CRT group found the data from the simulation output more useful. The hard copy group had a higher test score on questions relating to inventory theory as well.

Comparing the hard copy group to all other subjects who used the CRT shows that the hard copy group had superior performance and better test scores on inventory understanding. The results on the usefulness of information are mixed.

These data do not support Hypothesis 1. One possible explanation for this finding is the difference in room and environmental conditions. The CRTs were located in a separate part of a large terminal room; the hard copy terminals had better lighting and more space. It is also possible that a newness of graphics and the terminals inhibited performance since most of the executives had used the hard copy, but not the CRT terminals before.

Graphical Versus Tabular Output

Hypothesis 2 predicts that groups receiving graphical output on a CRT will have higher scores than non-graphical treatments. Table 2 compares the CRT tabular treatments with the different graphical treatments omitting the hard copy terminal tabular treatment. The CRT tabular group found the simulation output more useful than the two graphics treatments for demand frequencies and had significantly lower scores on the test of inventory understanding. For the two groups receiving graphs of the simulation output, one group had a higher score on each of the tests and one graphics group reported significantly more enjoyment from the exercise than the tabular CRT group.

TABLE 2

CRT Tabular Versus Graphics

CRT Tabular (22)[1]		Graphics Probabilities (19)		Tabular + Graphics Probabilities (19)	
	Mean	Mean	t	Mean	t
Simulation output	6.36	5.76	1.73**	5.73	1.90**
Inventory test	56.82	68.42	1.69**	77.63	3.03**

CRT Tabular (22)		Graphics Simulation (16)		Tabular + Graphics Simulation (21)	
	Mean	Mean	t	Mean	t
Simulation output	6.36	5.28	1.98**	NS	NS
Inventory test	56.82	NS[2]	NS	70.24	1.83**
Probability test	49.00	66.67	2.10**	NS	NS
Enjoyment	5.71	6.56	2.26**	NS	NS

* $p \leqslant 0.10$
** $p \leqslant 0.05$
*** $p \leqslant 0.01$
[1] Number of subjects
[2] Not significant

The hypothesis is not confirmed for performance or the usefulness of information. However, the evidence suggests that the graphics groups developed a better understanding of the problem. Some of the evidence, though, is for two groups receiving probability graphs on a test designed to measure the understanding of inventory, not probabilities. One group receiving graphical output on the simulation also did better in the probability test. Thus, these results must be treated with caution.

Graphics and Tabular Versus Tabular on the CRT

Table 3 contains data to test the third hypothesis that subjects receiving both graphical and tabular output will have higher scores than graphics groups receiving only graphical output. The data in Table 3 shows that the only significant differences among the treatments are for the usefulness of demand frequency distributions and simulation output graphs. For the group receiving the graph of probabilities and tables of probabilities as well, the scores were higher on the inventory test than for the group that received the graph alone. For the graph of the simulation results the group

TABLE 3

Graphics Versus Graphics and Tabular on CRT

Means		
Graphics Probabilities (19)[1]	Tabular + Graphics Probabilities (19)	t
Inventory test 68.42	77.63	1.30*
Graphics Simulation (16)	Tabular + Graphics Simulation (21)	t
Simulation output 5.28	6.14	1.56*

[1] Number of subjects
* $p \leqslant 0.10$

TABLE 4

Analytic Versus Heuristics by Tabular or Graphics

	Number of Subjects					
Treatment	Heuristic	Analytic				
CRT Tabular	11	11				
CRT Graphics[1]	37	38				
Best Simulation		Group Means				
	Treatment	Heuristic	Analytic	F		Sig.
	CRT Tabular	136,762	133,064	Interaction	2.72	.10
	CRT Graphics	132,581	133,059			
Inventory test		Group Means		F		Sig.
	Treatment	Heuristic	Analytic	Interaction	4.12	.04
	CRT Tabular	61.36	52.27			
	CRT Graphics	64.19	76.97			
Frequency distribution output		Group Means				
	Treatment	Heuristic	Analytic	F		Sig.
	CRT Tabular	5.05	3.55	Treatment	.034	NS[2]
	CRT Graphics	4.72	4.03	Group	6.30	.01
Simulation output		Group Means				
	Treatment	Heuristic	Analytic	F		Sig.
	CRT Tabular	6.73	6.00	Treatment	3.71	.05
	CRT Graphics	5.84	5.68	Group	1.8	NS
Satisfaction		Group Means				
	Treatment	Heuristic	Analytic	F		Sig.
	CRT Tabular	3.45	2.68	Treatment	1.64	NS
	CRT Graphics	3.86	3.21	Group	4.90	.03

[1] Includes both types of graphics, those with and without tabular data
[2] Not significant

receiving both graphics and tabular information reported greater usefulness for the simulation output compared to the group that received graphics alone. These results give limited support to the hypothesis, though again the inventory test score is the significant variable for groups receiving the probability treatment.

Heuristic Versus Analytic Decisionmakers

The final hypothesis predicts that heuristics will have higher scores for graphical treatments and analytics will have higher scores for tabular treatment on the CRTs. Table 4 shows the results of a two way analysis of variance for subjects in the CRT group receiving only tabular output compared with those who received graphical treatment on the CRTs. These groups are further partitioned into heuristic or analytic based on median test scores (a median of 2.38 with a range of 1 to 4).

Table 4 demonstrates the importance of considering cognitive style in designing the mode of presentation for an information system. In tests of the second hypothesis, no differences between tabular presentation on the CRT and graphics were found without controlling for decision style. However, Table 4 shows that the best simulation value was better under graphics and that most of superiority was in the heuristic group, that is, heuristic decisionmakers in the graphics treatment group had the best (lowest cost) simulation results. There is almost no difference between treatments for the analytics. This finding is in the direction hypothesized, at least for heuristics.

TABLE 5

Heuristic vs Analytic for Treatment

Inventory Test	Group Means				
Treatment	Heuristic	Analytic	F		Sig.
CRT Tabular	61.36 (11)[1]	52.27 (11)	Treatment	3.62	.03
Graphics Simulation[2]	60.53 (11)	76.39 (18)	Group	2.87	.09
Graphics Probabilities	68.06 (18)	77.50 (20)			
Frequency distribution output	Group Means				
Treatment	Heuristic	Analytic	F		Sig.
CRT Tabular	5.05 (11)	3.55 (11)	Treatment		NS
Graphics Simulation	4.32 (19)	4.25 (18)	Group	6.43	.01
Graphics Probabilities	5.14 (18)	3.82 (20)			
Satisfaction	Group Means				
Treatment	Heuristic	Analytic	F		Sig.
CRT Tabular	3.45 (11)	2.68 (11)	Treatment		NS
Graphics Simulation	3.82 (19)	3.14 (18)	Group	4.85	.03
Graphics Probabilities	3.92 (18)	3.27 (20)			

[1] Number of subjects

[2] Includes both types of graphics, those with and without tabular data

It is interesting to note that the results for the test of inventory understanding exhibit significant interaction, but in the other direction from performance. Taken as a whole, the graphics groups have had the highest scores. However, here the differences are greatest for analytics. The analytics in the graphical treatment group had the highest test scores, contrary to the hypothesis.

For reported usefulness of the frequency distributions and simulation output, heuristics scored highest, though the results are statistically significant only for the first of these variables. Finally the heuristics were more confident of the answers and satisfied with the exercise than the analytics.

Table 5 contains a further analysis of decision style; it compares the results for heuristics and analytics by three types of treatments. As seen in the test of hypothesis 2, the probability groups performed best on the inventory tests, even though one expects the graphical simulation output groups to perform best on this test. Table 5 shows decision style also affects these results. Analytics had high performance on the inventory test regardless of which graphical treatment they received. The unexpected findings came entirely from heuristics who performed better on an inventory test under the probability treatment. The other significant findings are consistent with those in Table 4.

6. Implications and Limitations

As in any experimental situation, there are limits to the study. First, one can question how typical the executives in the sample are compared to other decision makers. The structure of the problem was identical for all treatments. Also the realism of the problem was limited in order to conduct a laboratory experiment.

Given these limitations what are the implications of the research? From the experiment it is not possible to determine why the results occurred. However, based on this study and the research described earlier, one can speculate on possible causes for the results.

Contrary to the hypotheses, the tabular groups on the hard copy printing terminal had the best performance scores in the experiment. One reason for this finding may be the lack of experience decisionmakers have with graphics and CRT terminals. It appears that the users of these systems may need to work both with CRT and graphics presentations for a while to become accustomed to this mode of presentation. For example, Scott Morton [9] reported extensive training was required to prepare managers to use his system.

The results of this experiment indicate the importance of considering decision style in planning the mode of presentation of information. There is evidence that heuristics and analytics respond differently to graphics treatments. The results in Tables 4 and 5 are consistent with speculation that analytics may have a model in mind when beginning the exercise. If this is true, the mode of presentation would be relatively less important to them because they used output data to confirm or disprove their prior model.

Heuristics, on the other hand, performed better under graphics treatments where they could see a picture of the data. Heuristics may have relied on the displays more due to their lack of an *a priori* model. Having no standard set by a model, heuristics reported more confidence and satisfaction with the exercise than analytics.

The results of this experiment, speculation concerning the results, and prior research suggest some implications for design. First, differences have been observed in user reactions and/or performance based on the medium for output from a computer-based system. For example Scott Morton [9] and Lucas and Neilsen [7] suggest that it may take a relatively long period of time for computer-based graphics to make a difference in decison making. Designers must be prepared to invest in training and to go through a series of design and redesign cycles as users become familiar with graphics and request changes. There is also limited evidence that including the option for both tabular and graphics data is a good policy.

Decision style appears to be an important design variable. For example, the designer should consider the possibility that analytics approach a problem with an existing model. For these individuals the information provided by a system may be used to prove, disprove or modify a model. This type of information is different from the information used by a heuristic decisionmaker who may be just trying to find a problem. The existence of these different possibilities suggests that systems need to be highly flexible and contain a large number of options to suit decisionmakers with different decision styles. For example, the analytical decision maker may prefer a decision support system containing models while the heuristic decision maker may prefer a data analysis facility to support inductive problem solving.

One suggestion for decision style in design is to test for it in advance (Gerrity [4]). A problem with solutions like this is the lack of research results to indicate what the designer should do given a particular outcome on a test for decision style. The suggestions above for analytic versus heuristic users is based more on speculation than experimental results.

Another approach is to stress significant user involvement in the design of systems (Lucas [5]). The basis of this suggestion is that users will consciously or unconsciously influence the design of the system to be consistent with their decision style and other contingent variables. For voluntary systems like those designed for decision support, user understanding and influence in design may be the key to the development of the most appropriate mode of presentation.[4]

[4]The author would like to acknowledge the considerable assistance of Professor Charles Holloway in this research. He was instrumental in all aspects of the project and has made a significant contribution to the research reported here.

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