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DECISION SUPPORT SYSTEM EFFECTIVENESS: A REVIEW AND AN EMPIRICAL TEST*

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Despite the increasing popularity of decision support systems (DSS), effectiveness of such systems remains unproven. Past research claiming usefulness of the DSS has relied largely on anecdotal or case data. The relatively few laboratory experiments report mixed results regarding the effects of a decision aid. This study reviews the results of prior investigations and examines the effectiveness of DSS-aided decision makers relative to decision makers without a DSS over an eight-week period. An executive decision making game was used in two sections of a business strategy course. Three-person teams in one section used a DSS while the teams in the other section played the game without such an aid.

Various measures of decision quality were recorded. Overall, the groups with access to the DSS made significantly more effective decisions in the business simulation game than their non-DSS counterparts. The DSS groups took more time to make their decisions than the non-DSS groups at the beginning of the experiment. However, the decision times converged after the third week.

The DSS teams reported investigating more alternatives and exhibited a higher confidence level in their decisions than the non-DSS groups, but these differences were not statistically significant.

(DECISION SUPPORT SYSTEMS; INFORMATION SYSTEMS; EVALUATION; MAN-MACHINE SYSTEMS)

1. Introduction

Applications of Decision Support Systems (DSS) have become more common within the last decade. Similarly, the level of research activity has risen also (Sprague and Carlson 1982, Blanning 1983). Early empirical research in MIS, much of which is applicable to DSS, has been summarized by Dickson et al. (1977), Courtney et al. (1983), and Jarvenpaa et al. (1985) and is not reviewed here. Elam et al. (1986) present a review of recent DSS literature. Most of the current research investigating DSS has been aimed at determining optimal design parameters and development processes for implementing the MIS/DSS. A recent example is Dos Santos and Bariff (1988). An underlying assumption of such studies is that use of a DSS will increase the effectiveness of decisions and/or the efficiency of the decision process. While this assumption seems intuitively obvious, results of previous experimental studies are mixed. In some cases, use of a DSS increased decision quality. However, in others it did not.

One purpose of this paper is to review available empirical evidence regarding effectiveness of DSS. Possible reasons for the inconsistencies in the results of prior studies are discussed. Then the paper reports on a simple laboratory experiment to assess the effectiveness of a DSS in a task environment characterized by uncertainty in competitors' actions and economic conditions. The decision tasks included production decisions, cash management and investment decisions, and plant expansion decisions. The DSS was built using Interactive Financial Planning System (IFPS).

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The paper is organized as follows. §2 gives a summary of previous research. §3 proposes the hypotheses for the study. §4 describes the experiment. §5 presents the results of the experiment. §6 discusses the results and provides suggestions for future studies.

2. Previous Studies

We organize our discussion around the four approaches to empirical MIS/DSS research identified by Van Horn (1973): case studies, field studies, field tests, and laboratory studies. The distinction between field studies and field tests is that the former usually has no experimental control whereas in the latter the researcher attempts to manipulate some aspect of the information system and control for extraneous factors that may influence results. Table 1 lists representative studies of all four types.

The majority of claims regarding the benefits of DSS are based on case and field studies. Ferguson and Jones (1969), Simon (1977), Bass (1983) and numerous articles in trade publications (for example, Horwitt 1984) claim usefulness of DSS based on case studies. Many field studies showing improved decision making from DSS/MIS also exist. Examples include Garrity (1963), Dean (1968), Gallagher (1974), Keen and Scott Morton (1978), Alter (1980), and Wagner (1980). While numerous case and field studies have been conducted, field tests and laboratory experiments are relatively sparse. This is unfortunate as the latter two methods use greater experimental control and consequently allow for stronger inferences to be drawn. Results of representative field tests are reviewed first.

Fudge and Lodish (1977) reported results of a field test to evaluate the effect of the CALLPLAN model (Lodish 1971). Participants with access to the model had 8.1% higher sales than their counterparts. In another field test, Edelman (1981) estimated the benefits of IRIS, a DSS installed at RCA. He concluded that the divisions using the DSS had lower costs than those which did not. On the other hand, Gochenouer (1985) studied the use of DSS at Harris Corporation and, using change in salary as a performance measure, reported that employees not using the computer outperformed those who did. The performance measure reflected benefits to the individual and not to the company, but the two presumably were correlated. Thus the results of these field tests are inconclusive. Field tests are relatively sparse in DSS research because it is difficult for the experimenter to control the use of a DSS in an organizational setting.

Most notable of the laboratory studies are what are collectively known as "The Minnesota Experiments." These studies have been summarized by Dickson, Senn and Chervany (1977). While these studies set the stage for experimental research in MIS, their emphasis was on determination of optimal characteristics of an information

TABLE 1

Representative Case, Field, and Laboratory Studies in DSS Effectiveness

CASE STUDIES
Ferguson and Jones (1969), Simon (1977), Bass (1983), Horwitt (1984)
FIELD STUDIES
Garrity (1963), Dean (1968), Gallagher (1974), Keen and Scott Morton (1978), Alter (1980), Wagner (1980)
FIELD TESTS
Fudge and Lodish (1977), Edelman (1981), Gochenouer (1985)
LABORATORY STUDIES
Joyner and Tunstall (1970), Benbasat and Schroeder (1977), King and Rodriguez (1978), Chakravarti et al. (1979), Benbasat and Dexter (1982), McIntyre (1982), Dickmeyer (1983), Eckel (1983), Aldag and Power (1986), Goslar et al. (1986), Cats-Baril and Huber (1987)

system as opposed to the effects of availability of a system. These studies, in general, concentrated on information storage, retrieval, and presentation as opposed to decision modeling (e.g. Chervany and Dickson 1974). Those studies which did examine effects of availability of a decision aid (e.g. Benbasat and Schroeder 1977) are included in the following review. We were able to identify several other studies by searching journals such as *Management Science, Decision Sciences, MIS Quarterly,* and *Journal of Accounting Research* as well as an extensive bibliography of DSS literature by Elam et al. (1986). These studies are reviewed below. The laboratory studies are also summarized chronologically in Table 2. It should be noted that most of the studies investigated other issues in addition to availability of a DSS. Table 2 includes a summary of the studies only from the viewpoint of effect of availability of a DSS on decision outcome variables. Thus there may be other dependent and independent variables which were investigated in these studies but are not included in Table 2.

We also point out that the studies included in this review were not, in many instances, clear on the characteristics identified in Table 2. Our summary of these studies is based on the consensus of four MIS faculty members (including the first two authors) who read all of the papers. First we discuss the laboratory studies that have detected a positive effect of availability of MIS/DSS. Then we describe studies that found insignificant or even negative effects of use of a DSS on decision quality.

Benbasat and Schroeder (1977) employed three decision aids: forecasts of demands, suggested outputs, and optimal order quantity and reorder points based on the Wagner-Whitin algorithm. They found that even crude decision aids improved cost performance over simple intuition. They also noted that subjects with decision aids took longer to make decisions than their counterparts.

McIntyre (1982) evaluated the impact of judgment-based marketing models, employing a version of the CALLPLAN model (Lodish 1971), and found improved average profits for participants who had access to the model. Benbasat and Dexter (1982) evaluated the effect of a decision aid based on a simulation model. The decision environment was a multiperiod inventory/production game in which the participants made three decisions: an order point, an order quantity and the daily production for the next 20 days. They concluded that the participants with a decision aid had a higher profit performance than the ones without such an aid. The participants in the study were classified as low vs. high analytics, based on the Group Embedded Figures Test (GEFT) developed by Witkin et al. (1971). The researchers found that high analytics with the decision aid took more time to make decisions than the ones without the aid. However, low analytics with the decision aid took approximately the same amount of time to make decisions as low analytics without decision aid. Thus they concluded that the decision aid improved decision performance, and that the availability of a decision aid increased decision time for high analytic decision makers.

Dickmeyer (1983) tested TRADES, a computer-based, interactive financial model to assist university administrators in making decisions on faculty size, salaries, tuition and new investments. In this experiment, one group of subjects used TRADES while the other group was provided with a printed university forecast. The subjects were asked to rank-order a number of five-year financial policies. Users of TRADES were found to make more policy preference changes than the nonusers. That is, the model helped the users in developing their preference functions. Eckel (1983) reported that users who could get computer supported budgets and projections under different scenarios made better decisions than those who could not.

However, results of laboratory experiments have not always supported the usefulness of DSS. Joyner and Tunstall (1970) tested CONCORD (CONference COoRDinator), a program to help groups of decision makers apply a satisficing model. They reported that users of this program did not perform any better than the nonusers in solving

TABLE 2

A Summary of Laboratory Studies of DSS Effectiveness

Study	Nature of DSS Support	Type of Decision	Performance Measures	Length of Experiment	Group (G) or Individual (I) Decisions	Detected Relationship between DSS Usage and Performance
Joyner and Tunstall (1970)	CONference COoRDinator	human relations	quality of decision as assessed by 3 raters	two 40-min sessions over 2 days	G	no significant increase in decision quality
Benbasat and Schroeder (1977)	forecasts, suggested decision outputs	single product inventory production	cost, decision time	ten decisions representing 20 periods each, length two to three hours	I	DSS users had lower cost, but took longer to make decisions
King and Rodriguez (1978)	SICIS, an information system including competitor data	corporate strategic planning	quality of decision as assessed by 3 raters	one decision, but DSS used over a semester	I	no significant increase in decision quality
Chakravarti et al. (1979)	ADBUDG, advertising budget model based on decision calculus	advertising expenditures	profits, estimates of parameters of underlying model	six to twelve decisions over 9 weeks	I	DSS users had lower profits, no relationship between DSS usage and prediction of parameters
Benbasat and Dexter (1982)	simulation model	single product ordering and scheduling	profit, decision time	ten decisions representing 20 periods each, length two to three hours	I	DSS users showed increased profits, low analytics without the aid performed the worst even though low analytics with the aid performed as well as the high analytics; high analytic subjects with DSS took longer to make decisions
McIntyre (1982)	a decision calculus model, similar to CALLPLAN	promotion allocations	profit, confidence, volatility in profits, rate of decision improvement	nine decisions, length unknown	I	DSS users showed increased profits, greater volatility in profits, and faster rate of profit improvement

Dickmeyer (1983)	TRADES, a decision aid for university planning	university budget planning	change in policy preferences	one session	I	DSS users showed increased changes in policy preferences
Eckel (1983)	budget projections	production, advertisement	profit, number of alternatives, amount of information requested	six decisions, one decision per week	I	DSS users showed increased profits and greater information acquisition. Insignificant difference in number of alternatives examined
Aldag and Power (1986)	DECision AID, a DSS developed by the authors	strategic management cases	quality of decisions assessed by raters, confidence	one session with DSS, 1 without, length unknown	I	no significant differences in decision quality or confidence
Goslar et al. (1986)	IFPS-based DSS for the specific problem	marketing strategy	performance (requested analysis turned in = 1, 0 otherwise); time, number of alternatives, confidence	one session, over a day	I	no significant differences due to availability of DSS
Cats-Baril and Huber (1987)	Interactive heuristics delivered either with pen-and-paper or a computer	career planning	quality of career plan as assessed by raters, confidence, number of alternatives	one decision, length of session unknown	I	users with interactive heuristics showed improved decision quality, no significant effect of delivery using a computer. Negative effect on confidence but positive effect on number of alternatives
This Study	IFPS-based DSS for the specific problem	multi-product production decisions, securities, plant expansion	profit, volatility in profit, decision time, confidence, number of alternatives examined	eight decisions, one per week; one practice session	G	DSS users showed increase in profits and reduction in volatility; No overall differences in time, alternatives, or confidence

human relations problems. Chakravarti et al. (1979) tested a version of ADBUDG, the decision calculus model proposed by Little (1970), and reported that the model users actually earned less profit than the nonusers.

King and Rodriguez (1978) comprehensively evaluated an information system in terms of attitudes, value perceptions, information usage and decision performance. They concluded that decision performance (subjective ratings by three professors) of the group using an MIS did not differ significantly from the group without access to the system.

Aldag and Power (1986) tested an interactive heuristic program called DECAID (DECision AID). This DSS was used by one group of students in solving a case problem (Power and Rose 1977) while another group of students solved the same case without such help. Both groups then solved a second case. This time, the group initially exposed to DECAID did not use it while the other group did. The students were then asked to prepare written case analyses. Three raters assessed these analyses, and no significant differences in performance were detected.

Goslar et al. (1986) investigated the effects of DSS availability, training, and data availability. They had several marketing executives analyze a case using various levels of these factors. They did not find a significant main effect of DSS availability on decision performance, number of alternatives considered, time required to reach decision or perceived confidence.

Cats-Baril and Huber (1987) examined the effectiveness of a DSS in an especially ill-structured problem, career planning. They found that decision aids provided in the form of interactive heuristics had a positive effect on decision quality (measured as ratings of developed career plans by four career counselors). However, the subjects using the decision aid on the computer did not outperform those using the same interactive heuristics with paper and pencil.

In summary, field and laboratory tests investigating superiority of DSS over non-DSS decisions show inconclusive results. Aldag and Power (1986) also report mixed results on the benefits of a DSS, based on their review of several other earlier experimental studies which are not covered in this paper. There are two explanations for the pattern of inconsistent results noted in previous studies. First, it is possible that introduction of a DSS does not generally result in increased decision performance. Second, methodological limitations and differences between investigations may account for part of the inconsistencies. Characteristics of the empirical studies which may explain their conflicting results are examined below.

All of the studies (e.g., King and Rodriguez 1978) where performance scores were based on subjective ratings did not show a significant effect of a DSS. As noted by Keen and Scott Morton (1978), 'hard' measures of decision quality (e.g., income, market share or the like) would be more accurate indicators of decision performance.

Of the six studies showing no improvement in performance due to use of a computer-based DSS, four were based on a one-time measurement of performance. In reality, a DSS is likely to be used continually rather than just once. Similar to most recorded results that introduce change in an organizational setting, one would likely expect an initial decrease in performance. Thus a longitudinal study may offer a better evidence of the effectiveness (or ineffectiveness) of a DSS.

In most studies reviewed here, the decision aids were developed by the researchers. The subjects could use a 'black box' to help them in decision making. In limited cases it was possible for the subjects to investigate alternate scenarios (e.g., Benbasat and Dexter 1982), but the users could not see the model and its underlying assumptions. The last few years have witnessed an impressive growth in the modeling languages available for building DSS. The most powerful of these are referred to as DSS generators (Sprague 1980). These are high-level, end-user languages which allow quick development of a model. These DSS generators are interactive and fairly easy to use. Most commonly used financial functions are also usually built into the system. Some offer Monte Carlo simulation as well as simple 'what-if' scenario development for risk analysis. This interaction between user and DSS has been considered a major characteristic of DSS. Examples of such DSS generators include EXPRESS, IFPS, CUFFS, FCS, etc. A brief summary of some of these generators is given by Horwitt (1984). A decision aid developed using such DSS generators could offer more 'power' and flexibility to the subjects through ease of use of the DSS, convenient what-if analyses, and an ability to better understand and modify the model relationships than would be available with a FORTRAN or APL model. While some field studies have reported the uses/benefits of such DSS generators (for example, Wagner 1980), only one laboratory experiment (Goslar et al. 1986) has been conducted with a DSS built using these programs. Goslar et al. did not find a significant main effect of DSS availability on decision performance. However, they did not let the decision makers use the DSS directly. The decision makers could only specify the types of 'what if' analyses they wished to run. This written request was then processed by another individual and the results were returned to the decision maker. This process removed the computer-user interaction, a major part of DSS technology. Goslar et al. also found that the decision makers with access to the DSS actually considered fewer alternatives than those with access to the DSS. Given that the DSS aided decision makers had to prepare a written request and wait for the answers to 'what if' questions, this result is not surprising. This mode of use of DSS may have inhibited the spontaneity of interrogation, resulting in fewer analyses than would be the case with an interactive DSS.

With one exception (Joyner and Tunstall 1970), studies reviewed in this paper have focused on an individual decision maker as opposed to a group. Many complex decisions, such as investment in plant and equipment, are in practice group decisions. It is possible that a DSS may prove to be more effective if used by a group rather than by an individual in such decision tasks. DeSanctis and Gallupe (1987) identify three levels of Group Decision Support Systems (GDSS). They list DSS containing budget allocation and forecasting models as the level 2 GDSS. These are designated as appropriate decision aids for groups facing resource allocation tasks with uncertain future events. However, the effectiveness of such decision aids in complex tasks requiring a group decision has not been empirically tested before.

The study reported in this paper attempts to address the limitations cited above. First, it tested a DSS built using IFPS, a commercially available modeling language allowing 'what-if' analysis. Second, the decision setting was a semistructured problem, requiring decisions for production, investment, and plant expansion. Third, the performance measures were "hard," quantifiable ones, e.g. net earnings. Fourth, the study was conducted over eight experimental periods to allow for an examination of longitudinal effects. Finally, the participants in this experiment made decisions in groups.

3. Hypotheses

The hypotheses were designed to examine the relative performance of DSS groups with non-DSS decision making counterparts on several dimensions. The first hypothesis proposed that introduction of a DSS would result in higher levels of decision making performance. This is consistent with previous claims of superiority of computer support for general decision making (Garrity 1963; Dean 1968; Ferguson and Jones 1969; Gallagher 1974; Keen and Scott Morton 1978; Wagner 1980; Alter 1980; Bass 1983).

Hypothesis 1. DSS aided groups will show higher profit performance than non-DSS aided groups.

A second hypothesis was proposed to examine volatility of performance of the DSS versus non-DSS groups. Previous studies investigating potential benefits of DSS that have used 'hard' criteria have generally employed dependent measures such as profit or return on investment. Only McIntyre (1982) examined variance in performance of DSS users as a dependent variable. Hypothesis 2 posits that another potential benefit of a DSS is a reduction in the diversity of performance of groups using a DSS. Introduction of a DSS should assist decision makers in reducing effects of uncertainty. Therefore, it is expected that the volatility of performance should be less in these groups. Such a reduction in variance of the performance of decision making groups can be an extremely important outcome. For example, financial analysts often examine stability of performance as a critical factor in investment decisions. Studies examining risk and decision making suggest that decision makers generally prefer alternatives associated with less variance or risk in the potential outcomes. Thus, Hypothesis 2 introduces variance in group decision making performance as an important factor that should be considered in examining the performance of decision makers using a DSS.

Hypothesis 2. DSS aided groups will show less variance in profit performance than non-DSS aided groups.

A third hypothesis evaluated the effect of the DSS on time required to reach the decision. This may be viewed as an indirect examination of the effect of the DSS on efficiency of the decision making process. Alter (1980) cites increased efficiency of decision making as one potential benefit of a DSS.

Only a few studies have examined the effect of using a DSS on amount of time required to reach a decision and none of these have used group decision tasks. Because of the longitudinal design of our study, time spent on decision making can be evaluated over an eight-week period. This allows for examination of whether the DSS groups will become relatively more efficient than non-DSS groups as successive iterations of the decision are made. Following Alter (1980), efficiency is defined in terms of the speed of the decision making process, rather than as a ratio of some output to inputs.

Initially, it may be expected that users of a DSS will require greater time to reach a decision as they familiarize themselves with the system. Such results frequently are noted in planned change/intervention literatures (Huse 1980). However, advocates of DSS propose that such decision tools should shorten the time necessary to make a decision. Therefore, Hypothesis 3 examined the effect of DSS on time spent in the decision making process.

Hypothesis 3. DSS aided groups will take less time to reach a decision than non-DSS aided groups.

Another proposed benefit of DSS is comprehensiveness of decision making. Use of a DSS has been hypothesized to increase decision quality by allowing more alternatives to be examined (Alter 1980). Cats-Baril and Huber (1987) found a positive relationship between DSS availability and number of alternatives considered, while Eckel (1983) and Goslar et al. (1986) found no significant relationships. Thus, Hypothesis 4 examined the effects of the DSS on the number of alternatives that were evaluated.

Hypothesis 4. DSS aided groups will consider a greater number of alternatives than non-DSS aided groups.

The final hypothesis investigated the effect of DSS on confidence of the decision makers. While some investigators have examined relationships between DSS use and user attitudes such as satisfaction and confidence (Aldag and Power 1986; King and Rodriguez 1978; McIntyre 1982), results of these studies are mixed. No studies examining affective reactions have been conducted using group decision tests. Hypothesis 5 examined the effect of DSS on confidence of the decision makers.

Hypothesis 5. DSS aided groups will report greater confidence in their decisions than non-DSS aided groups.

4. Method

4.1. *Subjects*

Participants in this study were 96 senior level undergraduate students enrolled in a business policy course in a midwestern university. An integral component of the course is a strategy simulation that requires students to work as 'management teams' in making decisions for their firm. Two sections of this course were chosen for the study. Each section consisted of 48 students and was taught by the same professor during the semester that the study was conducted.

Students were grouped into three-person teams responsible for the operations and performance of an organization. Fifteen percent of a student's grade was contingent on their group's performance in this decision-making simulation. Because we felt that the groups would be more likely to attribute the group's performance to themselves under self-selection rather than under imposed groups, subjects were allowed to self-select their three-person management groups.

Previous studies using students in simulated decision tasks have reported differences in performance due to academic background or ability. For example, Seginer (1980) found a relationship between academic ability and game performance. Similarly, Chervany and Dickson (1974) found quantitative ability to be associated with increased decision performance. On the other hand, Dill (1961) and Kozar (1972) found no relationship between such factors and decision performance. Since groups were allowed to select their members, measures of student GPA, major, and course grade were taken to identify possible sources of variability in performance among teams. Chi square tests employing these three factors one at a time indicated no significant differences between the DSS and non-DSS groups.

4.2. *Task*

Subjects participated in a computer assisted simulation that modeled a business environment. The specific game selected was a version of The Executive Game (Henshaw and Jackson 1983). Students assumed the role of upper level managers and made group decisions on investment in plant and equipment, purchase or sale of securities, and a series of decisions for each of three product lines. These product decisions included sales price, production volume, production budget, marketing budget and design/styling budget. Each team was responsible for 17 decisions per quarter. Each decision session represented a three-month period. One practice decision was made, followed by eight quarterly decisions. Quarterly decisions were made once a week, thus subjects participated for an eight-week period representing two years.

In our version of the game, each industry had eight firms which provided a variety of products at different prices and qualities aimed at different market segments. The demand for products was a function of prices to be charged by the firms as well as of general economic conditions which were measured in terms of a business index. The business index determined the overall demand for the product line and the quality mix within that product line. There was also seasonality in product demand during each of the four quarters. The products were kept generic in order to minimize effects of someone's familiarity with any particular industry. The game simulated an environment in which the management teams competed against each other. All teams were equally affected by the prevailing economic conditions, purchaser attitudes and the actions of other firms in the industry. Their objective was to maximize long-term earnings by making 'right' decisions on product-mix, production quantities, investment and plant expansion.

After the teams submitted each quarter's decisions, the course instructor entered all decisions into the computer, the game program simulated the quarterly performance, and results were presented to each team. Each team also received aggregate industry level information such as industry reports and business index forecasts. In addition, each team was provided information including overall profits/losses, cash flow, financial status, and a plant report for that firm. For each of the three product lines, an income/expense summary and a production/sales/inventory report was also distributed. The nature and amount of information provided by the computer printouts was the same for both DSS and non-DSS groups. The game parameters were identical for the control (non-DSS) and experimental (DSS) groups.

4.3. *Procedures*

One of the course sections was arbitrarily selected to serve as the control group that would make decisions without assistance of a DSS. The second course section was the experimental group and was given instruction in the use of a specific DSS. A detailed explanation of the DSS is contained in §4.4.2. At the beginning of the semester, the instructor introduced the game and reviewed the procedures to be used. Subjects were told that demand for products was affected by general economic conditions, as well as joint actions of their decisions with those of other firms in their industry. At this time, the 48 students in each section were grouped through self-selection into three-person teams. The resulting 16 teams were then randomly assigned to one of two industries, each industry being a competitive environment consisting of eight companies. Teams within each industry were told that they were in competition with each other. No dummy teams were involved in this simulation. The introduction, explanation of the game and assignment of three person teams were identical for the DSS and non-DSS sections.

Teams in both the DSS and non-DSS sections were informed that the first week's decisions would allow them to become familiar with the procedures and would be considered a practice session. The control (non-DSS) section then proceeded with the initial practice decision, followed by the simulation for an eight-week period. The experimental (DSS) section received instruction in the use of the DSS, made initial practice decisions and then began the eight-week simulation.

4.4. *Measures and Operationalizations*

4.4.1. *Independent Variable.* The purpose of this experiment was to evaluate the effectiveness of DSS by examining the decision performance of DSS versus non-DSS groups in a semi-structured task. Therefore, the only difference between the two sections was the introduction of a DSS in the experimental group. Unlike many other experimental studies in MIS, no aspects of the DSS were varied. The objective of this research was to determine if having a fairly typical DSS makes any difference at all, rather than to determine the optimal parameters of a DSS. The decision problem in this game is representative of a combination of operations and strategic decisions and was complex because of the uncertainty in competitors' actions and the economic conditions. Such a decision problem could benefit from a DSS. Once a general model of the decision problem is built, such a system could allow one to change the basic assumptions of the model. Using an interactive system, top management may be able to easily investigate the effect of various uncertainties by examining many 'what-if' scenarios.

4.4.2. *EXEC-DSS.* The decision support system in the study, EXEC-DSS, was built using a DSS generator, Interactive Financial Planning System (IFPS) (Execucom 1985). IFPS is very user friendly and can allow one to code the model in near-natural language. This feature greatly enhances the users' ability to understand and modify the model. IFPS is interactive and is set up in a spreadsheet format. It has 'what-if,' 'goal seeking' and 'Monte Carlo simulation' options. The 'what-if' option lets a user change either model parameters or relationships quickly and see their effect on the performance variables. The 'goal seeking' mode is converse of the 'what if' option and allows the user to determine the requisite level of certain variables in order to achieve a particular performance level (e.g. breakeven analysis). The Monte Carlo simulation option lets the user supply probability distributions of uncertain variables and generate probability distributions of performance variables after sampling trials. These features allow the user to quickly and easily consider various alternatives to deal with the uncertainty in the problem. We used the mainframe version of IFPS, but the model can also run on a microcomputer version. IFPS was selected because of its widespread use, a measure of "typicality," and its availability (Wagner 1980). The EXEC-DSS model could also be built using many of the other DSS generators mentioned earlier.

The EXEC-DSS is essentially a financial analysis model. It takes certain historical values, forecasts of demand and other variables, and produces reports containing information similar to that in the reports generated by the Executive Game. The model contains about 450 statements and consists only of calculations that participants could do without using the DSS. Further, the 'what if' and 'goal seeking' options of IFPS allow one to investigate the effect of various alternatives. One could also change the forecasts to analyze the effect of uncertainties.

A copy of the model was made available to each team in the DSS section. To run DSS, teams entered values of variables such as inventory and plant investment as well as their decisions. The model could then generate either reports similar to the ones produced by the game or print values of individual performance variables. The user could consider other alternatives by using the interactive options mentioned earlier. The user could also change the relationships in the model. This was possible because the model contained descriptive rather than cryptic variable names, making understanding of the model relationships easier. A brief session with the DSS is listed in the Appendix. A complete listing of the model is available from the authors.

The first author introduced the DSS to the class section scheduled to use the DSS. Each team was given an explanation of the model, and the procedures necessary to use the DSS were reviewed. Groups in this experimental (DSS) section were not given any additional industry or firm information not available to groups in the non-DSS section. The DSS could be accessed independently by the teams through use of any of the readily available terminals in computer laboratories across the campus. There were no particular hours set for the teams required to use the DSS.

Introduction and explanation of this DSS took approximately 2 hours (two 50-minute lectures) out of a total of 45 lectures during the semester. The first lecture described the basics of IFPS planning language. The second lecture introduced the specific DSS and covered examples of its use in decision making. While Monte Carlo simulation option was mentioned, it was not covered in detail. A graduate assistant conversant with the DSS was available in a computer laboratory for two additional hours during the first week (practice week) to answer any questions about the use of IFPS or the DSS. During the two hours spent on DSS in the experimental group, the non-DSS section was taught by the course instructor. The topics covered were related to business policy in general and were not specifically concerned with the game simulation.

The decision-making process for both DSS and non-DSS teams consisted of examining historical as well as forecast data, developing alternatives, and analyzing them to arrive at financial decisions for each period. DSS teams had EXEC-DSS to assist in formulating decisions. The non-DSS teams could use a calculator or any other tools they wanted to use; they were not told about or given passwords for access to the DSS.

From observation of computer billing records while the game was being played and from conversations with members of the treatment group, it is believed that the DSS was used heavily and that all the teams used it for about the same amount of time. Unfortunately, all of the teams were using the same computer account (with individual password protection for datasets). Because of this, computer records were not available in a form that could identify the extent of use of EXEC-DSS by a particular team.

4.4.3. *Dependent Variables.* Previous studies have suggested numerous potential variables that could be used to evaluate the effects of a DSS on decision-making performance. Keen and Scott Morton (1978) have categorized these into effectiveness and efficiency measures, with effectiveness indicating quality or accuracy of decision and efficiency typically measured as speed or reliability. The decision simulation provided separate group performance data on aggregate firm performance (total revenue, net earnings, net cash flow and net assets) as well as performance of each of the 3 product lines (income, market share). As expected, the correlation between these items was high. Therefore, net earnings was chosen as a primary decision effectiveness variable as it represented the 'bottom line' measure of the group's performance. In addition, the teams were told in the introduction of the simulation that net earnings would represent the most important factor in evaluating group performance.

Efficiency of group performance was measured through self-reporting of the amount of time spent in decision making. In addition to turning in each quarter's decisions, each team was required to indicate the total amount of time spent by the group members in reaching that quarter's decisions. Total group time spent on decision was used as the primary efficiency measure.

Other self-reported measures of group outcomes were also included each quarter. Group members were instructed to record and report the number of alternatives[1] that were considered prior to finalizing the group's decisions. In addition, they were asked to assess their confidence in the quarterly decisions. Perceived confidence was measured on a ten point Likert-type scale.

5. Results

The simulation yielded a number of decision quality variables including market share and operating profit for each product line, total revenue and expenses, net cash flow, net assets, and net earnings. Since these outcome variables were highly correlated, only net earnings was included in the reported analyses. Results using other variables are available from the authors. A similar pattern of results was observed using these other variables.

Some of the teams failed to turn in their decisions on time during the last two quarters. Thus, their team decisions were not entered into the simulation for these two time periods and it resulted in a smaller sample size for those periods. A probable cause for it was the usual end-of-semester pressure. The exact sample size used to compute the means is noted in the tables.

The primary analysis consisted of analysis of variance (ANOVA) to determine the effect of presence of a DSS on the dependent variables of net earnings, time spent on decision, number of alternatives considered and confidence in decision. Because of the longitudinal design of the study, a repeated-measures ANOVA design (Winer 1971) was employed. The form of this model was:

$$\underline{\text{Dependent Variables}}$$
$$\left\{\begin{array}{l}\text{net earnings}\\ \text{time}\\ \text{confidence}\\ \text{alternatives}\end{array}\right\} = \mu_{\ldots} + \alpha\,(\text{Use of DSS}) + \beta\,(\text{Game Period}) + \epsilon.$$

[1] Since all of the decision variables were continuous variables, there could be an extremely large number of potential alternatives. Students were asked to count only the discrete combinations of decisions they had considered in reporting number of alternatives.

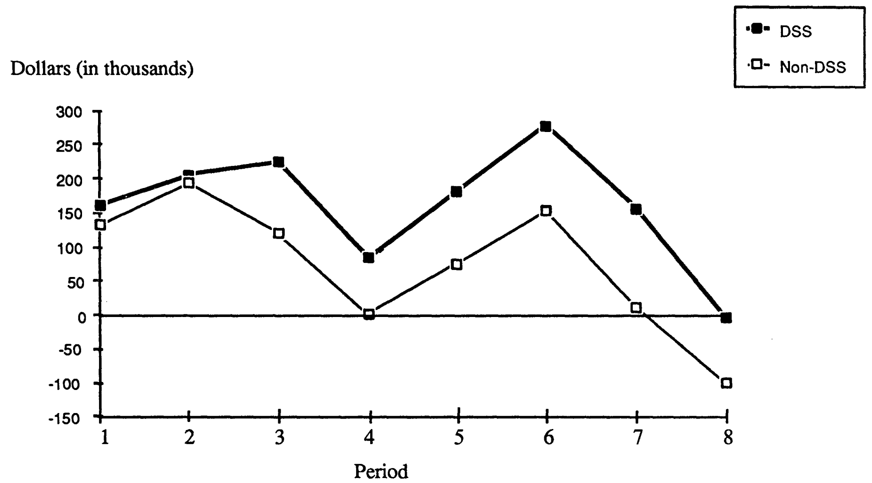

FIGURE 1. Average Net Earnings for DSS and Non-DSS Teams.

Because no a priori interactive effects were proposed, interactions were not included in the model. This model examined the influence of the DSS on each of the dependent variables over the eight-week period following the initial one-week practice decision.[2]

Hypothesis 1 proposed that DSS groups would make higher quality decisions than non-DSS groups. Results are presented in Table 3 and Figure 1. Figure 1 indicates that the two groups were subjected to similar economic cycles.

TABLE 3

*Effect of DSS Usage on Net Earnings**

Period	NET EARNINGS (Dollars) DSS (N)	Non-DSS (N)	Significance Level of the Difference
0	PRACTICE PERIOD		
1	161,172 (16)	132,489 (16)	n.s.
2	205,585 (16)	193,692 (16)	n.s.
3	223,488 (16)	120,596 (16)	n.s.
4	84,666 (15)	1,833 (16)	0.01
5	182,379 (16)	76,019 (16)	0.01
6	278,939 (16)	153,486 (16)	0.05
7	157,416 (12)	11,881 (7)	0.01
8	−3,720 (16)	−100,401 (5)	0.05
Overall	161,988 (123)	96,583 (108)	0.01

* The MANOVA procedure deletes any observation having missing data for any of the dependent variables. The net earnings figures reported here were calculated using all available data for each period. This allows a more comprehensive period by period examination by using data not included in the overall MANOVA test.

[2] Because multiple dependent variables were examined, hypotheses analyses were initially designed as a repeated measures MANOVA. However, a number of teams did not include self-reported data on amount of time spent, number of alternatives examined, and confidence during the last 3 weeks of the simulation. The MANOVA procedure could not be used since this analysis technique deletes all data for any observation containing missing data for any of the variables. The resultant sample was too small for adequate statistical power. Therefore, net earnings, time, number of alternatives, and confidence were examined independently. Analyzing the dependent variables separately does increase the likelihood of a collective alpha (Type I) error.

TABLE 4
Effect of DSS Usage on Variance of Net Earnings

Period	Standard Error of NET EARNINGS (Dollars) DSS (N)	Non-DSS (N)	Significance Level Difference
0	PRACTICE PERIOD		
1	18,547 (16)	15,127 (16)	n.s.
2	27,095 (16)	51,713 (16)	0.02
3	17,456 (16)	63,725 (16)	0.01
4	16,828 (15)	29,402 (16)	0.03
5	20,557 (16)	35,982 (16)	0.04
6	36,261 (16)	51,429 (16)	n.s.
7	21,088 (12)	90,098 (7)	0.01
8	17,626 (16)	108,532 (5)	0.01
Overall	10,914 (123)	18,670 (108)	0.01

Since eight time periods were present, the first analysis tested for an overall effect of the DSS on the combination of the eight period net earnings dependent variables. The DSS showed significant overall effects using Wilks' lambda test ($p < 0.05$). As noted in Table 3, the DSS groups outperformed their non-DSS counterparts in each quarter. This difference was statistically significant for quarters 4 ($p < 0.01$), 5 ($p < 0.01$), 6 ($p < 0.05$), 7 ($p < 0.01$), and 8 ($p < 0.05$).[3]

Hypothesis 2 posited that DSS groups would have less variance in their performance. The variance in net earnings was compared between DSS and non-DSS groups each quarter. Significance levels for the tests of equality of variance are contained in Table 4.

The DSS groups had less variability in group decision performance in seven of the eight quarters. The difference was statistically significant in six of the eight quarters. The overall analysis also showed that the DSS group had significantly less variance in net earnings ($p < 0.01$) over the entire eight-week experiment.

The impact of the DSS on decision efficiency was examined using time as the dependent variable. Since the self-reported time data were not provided by all teams each week, this analysis was conducted for each period only; no overall test was conducted for the full eight-week session. Results are presented in Table 5 and Figure 2.

DSS teams did use significantly greater time to reach decisions initially. The non-DSS groups made faster decisions during the first 3 quarters. However, there was no significant difference between time required to reach decisions in the last five quarters.

Hypotheses 4 and 5 evaluated number of alternatives examined and team members' confidence in their group's decision. These were analyzed for the eight quarters using the procedures outlined above. The DSS groups examined more alternatives in six of the eight quarters, although none of the differences were statistically significant. Similarly, confidence in decision was higher in six of the eight quarters. Again, however, none of these differences were statistically significant, largely due to the small sample sizes. These results are presented in Tables 6 and 7.

[3] Analysis of homogeneity of variance for Hypothesis 2 indicated nonhomogeneity of variance in net earnings between the DSS and non-DSS groups. Keppel (1982) and Myers (1972) note that the ANOVA procedure is robust with respect to violations of the homogeneity of variance assumption for between treatment effects (DSS vs. non-DSS). Subsequent analysis of Hypothesis 1 under conditions of homogeneity and nonhomogeneity revealed similar patterns of results. The ANOVA procedure is not robust to violations of homogeneity of variance for within subject effects (changes in a single treatment group across periods). However, none of the hypotheses examined this type of effect.

TABLE 5

*Effect of DSS Usage on Time Spent in Decision Making**

Period	TIME (hours) DSS (N)	Non-DSS (N)	Significance Level Difference
0	PRACTICE PERIOD		
1	5.55 (10)	3.58 (12)	.01
2	4.11 (11)	2.68 (11)	.05
3	3.95 (15)	2.26 (7)	.05
4	2.81 (10)	2.80 (5)	n.s.
5	2.86 (12)	3.13 (5)	n.s.
6	2.58 (6)	3.13 (4)	n.s.
7	2.38 (4)	1.80 (5)	n.s.
8	3.67 (5)	1.67 (3)	n.s.

* Use of the MANOVA technique for time, number of alternatives, and confidence resulted in too few observations for adequate hypothesis testing. Thus, no overall MANOVA results are reported. Figures reported in this table were calculated using all available data each period.

6. Conclusions and Discussion

Results of this study indicate that use of a particular DSS by 3-person teams resulted in significantly greater decision making performance. In the overall analyses of net earnings as well as in five of the eight quarters, the DSS groups produced significantly better decisions. In the remaining three quarters, the DSS groups also had greater earnings, but these differences were not statistically significant.

The results suggest that an additional benefit of the DSS was a reduction of variance in the decision makers' profit performance. While not previously considered as an outcome, this may represent a significant advantage of instituting a DSS. On the other hand, less variability in performance may not always be desirable. The decision aid may be limiting risk taking by encouraging uniform decision processes and outcomes. Given the significant differences in net earnings between the two groups, however, more stable performance would appear to be preferable.

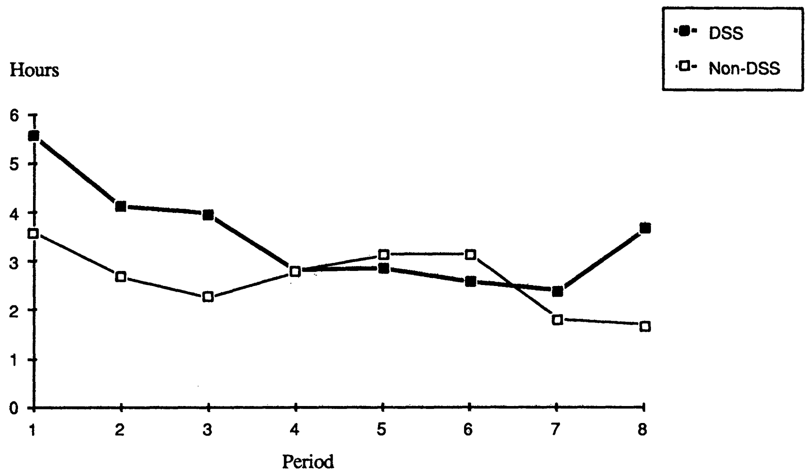

FIGURE 2. Average Time Spent in Decision Making.

TABLE 6

*Effect of DSS Usage on Number of Alternatives Examined**

Period	ALTERNATIVES DSS (N)	Non-DSS (N)	Significance Level Difference
0	PRACTICE PERIOD		
1	7.82 (11)	5.50 (12)	n.s.
2	7.27 (11)	4.00 (10)	n.s.
3	6.33 (15)	3.71 (7)	n.s.
4	5.10 (10)	2.40 (5)	n.s.
5	4.92 (12)	2.50 (4)	n.s.
6	3.00 (7)	7.25 (4)	n.s.
7	2.25 (4)	3.00 (5)	n.s.
8	5.80 (5)	2.00 (3)	n.s.

* Use of the MANOVA technique for time, number of alternatives, and confidence resulted in too few observations for adequate hypothesis testing. Thus, no overall MANOVA results are reported. Figures reported in this table were calculated using all available data each period.

In only the first three sessions did DSS groups take significantly longer to reach decisions. This pattern of results is consistent with a 'learning effect.' It may be expected that some period of time is required for users of a DSS to become familiar with the use of the support system, benefits may therefore appear only after a learning period. This lagged effect on decision performance may account in part for the results of some earlier studies showing no significant improvements in decision performance among DSS users.

DSS groups reported that they investigated more alternatives and had greater confidence in their decisions. Although not statistically significant, these findings were in the hypothesized direction in six out of the eight weeks.[4] In the remaining two weeks the mean number of alternatives and confidence are based on a smaller number of obser-

TABLE 7

*Effect of DSS Usage on Confidence in the Decision**

Period	CONFIDENCE DSS (N)	Non-DSS (N)	Significance Level Difference
0	PRACTICE PERIOD		
1	5.86 (11)	5.13 (12)	n.s.
2	6.27 (11)	5.86 (11)	n.s.
3	7.14 (14)	6.29 (7)	n.s.
4	7.20 (10)	6.50 (5)	n.s.
5	6.75 (12)	5.88 (4)	n.s.
6	7.14 (7)	7.88 (4)	n.s.
7	6.90 (4)	6.70 (5)	n.s.
8	6.86 (5)	7.50 (3)	n.s.

* Use of the MANOVA technique for time, number of alternatives, and confidence resulted in too few observations for adequate hypothesis testing. Thus, no overall MANOVA results are reported. Figures reported in this table were calculated using all available data each period.

[4] A sign test shows strong result in hypothesized direction. However, a MANOVA with repeated measures gives more conservative results.

vations. While many teams did not provide these self-reported data during the final four periods, it is interesting to note that DSS groups were much more likely to submit this information.

As a whole, the results indicate that the DSS groups reached better decisions in approximately the same amount of time. Thus, the DSS resulted in greater decision quality with only a short-term loss in efficiency of the decision process. The results indicate that future studies should incorporate a longitudinal design to more accurately assess cumulative effects of implementing a DSS. In addition, organizations implementing a DSS may not be able to realize immediate improvements in decision making performance.

Clearly, results of this investigation are bound by the nature of the decision task, subjects used, experimental design, and characteristics of the DSS that was employed. The decision task was complex, interdependencies existed between teams within an industry and the teams faced uncertain economic market conditions. Similar results might not be obtained in a different decision environment. However, DSS are usually designed for such uncertain and ill structured decision situations.

While subjects in our experiment were not decision makers in an actual organization, they were being prepared for such roles. A significant portion of the participants' grade was contingent on performance of the 'management team.' Each participant had an interest in the outcome of their team's decision. Care was taken to avoid the presence of a 'Hawthorne' effect by not mixing DSS and non-DSS groups within the two course sections. On the other hand, such an effect could exist between the two experimental conditions if subjects in the non-DSS section viewed themselves as deprived of the DSS that was available to their counterparts in the DSS section.

The results of this study may also be dependent on the experimental design employed. In our opinion, this design was an improvement over the others. It was a longitudinal experiment in contrast to most previous studies. Alternative designs such as that used by McIntyre (1982), where both control and treatment groups start without the DSS and a few periods later the DSS is introduced to the treatment group, could assist in separating 'learning' effects from DSS effects. Finally, designs that remove the DSS after some period of time could examine whether decision makers have improved conceptual decision making skills or simply become reliant on the DSS to formulate a solution.

Our results generalize only to a DSS of the type we used and only to the decision task we employed. However, the DSS was developed using a standard, commercially available DSS generator. Special features of such languages include an interactive, natural-language interface, what if, goal seeking options, and easy report preparation. Perhaps it is these features of the DSS generators that lead to better decisions. Clearly, this study needs to be replicated using other designs, decision tasks, and subjects before it can be claimed that such features will improve performance.

Our experimental procedures did not allow us to measure the amount of computer usage by each team. Thus, we were unable to evaluate the effect of the amount of time spent using the DSS on performance within the treatment group. Follow-up studies should attempt to establish a relationship between the extent of DSS usage and decision performance.

It appears appropriate to examine certain characteristics or attributes of DSS to determine what DSS components influence decision performance quality and efficiency of the decision process. Cats-Baril and Huber (1987) found that the "interactiveness" of a decision aid positively affected decision quality, regardless of whether the interaction was with a computer or with paper-and-pencil. This provides strong support for the use of interaction in decision-making process. A DSS built using a DSS generator offers ability to examine 'what-if' relationships in the decision process. This attribute of a DSS needs further study to identify optimal level of computer-user interaction. The nature of effects of advanced analysis capabilities such as goal seeking, Monte Carlo simulation for risk analysis, and optimization in a DSS environment also need to be studied. Ability to understand and modify a model built by someone else is another characteristic of such DSS that remains to be investigated. While the simple experiment reported in this paper has shown that a combination of these characteristics in a DSS resulted in better decision performance over those who did not have access to the DSS at all, it did not pinpoint the increased performance to any particular attribute(s) of the DSS. Future studies should attempt to isolate the effects of these characteristics of the current breed of DSS generators.

Our review of the literature on DSS effectiveness suggests that most previous studies do not show consistent signs of evolution. That is, the studies appear to have been conducted independently, without any progressive improvements in experimental design, DSS employed, or variables examined. We hope that our literature review will help other researchers in developing studies which will build on this earlier work. These future studies, when combined with the wealth of research in MIS design (Dickson et al. 1977; Courtney et al. 1983; and Jarvenpaa et al. 1985) will help in the development of future DSS.[5]

Appendix: Part of a Session with EXEC-DSS

(User input is underlined)

<u>LOGON USERID/PASSWORD SIZE(1000)</u>
READY
<u>IFPS</u>
INTERACTIVE FINANCIAL PLANNING SYSTEM-9.0
ENTER NAME OF FILE CONTAINING MODELS AND REPORTS
?<u>EXEC</u>
FILE EXEC PROCESSED
READY FOR EXECUTIVE COMMAND
?<u>MODEL GAME</u>
READY FOR EDIT, LAST LINE IS 10000
?<u>LIST</u>
A COMPLETE LISTING OF THE MODEL IS DISPLAYED.
?<u>SOLVE</u>
MODEL GAME VERSION OF 02/14/84--1 COLUMNS 165 VARIABLES
ENTER SOLVE OPTIONS
?<u>GENREPORT RESULTS</u>
A REPORT IS DISPLAYED GIVING OVERALL PROFITS/LOSSES, CASH FLOW, FINANCIAL STATUS AND A PLANT REPORT. IT ALSO INCLUDES AN INCOME/EXPENSE SUMMARY AND PRODUCTION/SALES/INVENTORY REPORT FOR EACH PRODUCT LINE. PART OF THE REPORT IS REPRODUCED BELOW:

<u>CONSOLIDATED REPORT</u>

<u>PROFITS AND LOSS</u>

TOTAL SALES REVENUE, ALL PRODUCTS		$1,790,680
TOTAL LABOR AND MATERIAL COST	$686,100	
COMBINED INVENTORY VALUE ADJUSTMENTS	$−49,478	
TOTAL MARKETING EXPENDITURES	395,000	
TOTAL DESIGN AND STYLING EXPENDITURES	75,000	
TOTAL WAREHOUSING AND SHIPPING COSTS	125,103	

[5] The authors thank Fritz Reiger who allowed us to conduct this experiment in his classes. They also thank James W. Gentry, Charles R. Greer, three anonymous referees and the departmental editor for their comments on earlier drafts of this paper. They also appreciate the help of Marilyn G. Kletke and Brenda Killingsworth in summarizing the results of studies reviewed in this paper.

DEPRECIATION	201,716	
ADMINISTRATION, ETC	265,870	
TOTAL EXPENSES		$1,699,311
TOTAL OPERATING PROFIT		$91,369
INCOME FROM SECURITIES		120,000
TOTAL TAXABLE INCOME		$211,369
TAX ON CURRENT INCOME		109,912
NET EARNINGS		$101,457
CASH FLOW		
TOTAL SALES REVENUE, ALL PRODUCTS	$1,790,680	
INCOME FROM SECURITIES	120,000	
TOTAL RECEIPTS		$1,910,680
TOTAL EXPENSES, LESS INV ADJ, DEPR	$1,547,073	
NEW PLANT INVESTMENT	0	
NEW SECURITIES INVESTMENT	0	
TAX ON CURRENT INCOME	109,912	
TOTAL DISBURSEMENTS		1,656,085
NET CASH INFLOW		$253,695
FINANCIAL CONDITIONS		
NET CASH ASSETS	$1,770,285	
INVENTORY VALUE	82,703	
PLANT AND EQUIPMENT VALUE	8,068,624	
SECURITIES	8,000,000	
NET ASSETS	$17,921,612	

ENTER SOLVE OPTIONS	
?WHAT IF	
WHAT IF CASE 1	
ENTER STATEMENTS	
?PRICE1=4.75	*WE CAN ENTER AS MANY NEW VALUES OR RELATIONSHIPS AS WE LIKE. OUR EXAMPLE INVESTIGATES EFFECT OF A NEW PRICE AND DEMAND FOR PRODUCT 1 ON NET EARNINGS.*
?DEMAND1 = 180000	
?SOLVE	
ENTER SOLVE OPTIONS	
?NET EARNINGS	*WE COULD ALSO REQUEST A COMPLETE REPORT BY USING GENREPORT.*

```
*****WHAT IF CASE 1*****
2 WHAT IF STATEMENTS PROCESSED
                         1
NET EARNINGS        89931
ENTER SOLVE OPTIONS
?QUIT
```

MORE WHAT IF'S CAN BE ENTERED HERE, BUT WE WILL QUIT.

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