THE USE OF SIMULATION AND GAMING
IN INFORMATION SYSTEMS RESEARCH

Working Paper No. 26

by

Theodore J. Mock*

Miklos A. Vasarhelyi**

John C. Fellingham***

July, 1973

*Associate Professor, University of Southern California

**Director of the Computer Center and Associate Professor
Pontificia Universidade Catolica de Rio de Janeiro

***Doctoral Candidate, University of California, Los Angeles

THE USE OF SIMULATION AND GAMING IN INFORMATION SYSTEMS RESEARCH

Research in management information systems and in information, communication or intelligence systems in general has grown significantly within the past decade. Yet although significant work is evident at both the theoretical level with the development of information economics and statistical decision theory and at the technical level as is evidenced by the development of complex on-line networks and advanced information storage and retrieval systems, little research which has focused upon information systems has utilized gaming and simulation techniques. Such techniques have been used by the authors in a series of related studies into information systems and decision processes. The use of simulation and gaming in this information systems context is critically examined and exemplified in this paper. As will be demonstrated, simulation techniques are useful for the analysis of complex decision models in which information alternatives are examined and for controlled empirical (experimental) analysis of information alternatives. The paper begins with a summary of a series of information economics experiments and the use of gaming therein. Within this context, discreet event simulation is utilized to estimate the value of more timely information in a fifteen period decision process which contains four random environmental variables. The second main part of this paper considers the use of less controlled gaming for the investigation of an on-line directive planning system.

THE USE OF SIMULATION AND GAMING IN INFORMATION SYSTEMS RESEARCH

GAMING AND SIMULATION APPLIED TO INFORMATION ECONOMICS

The first set of applications of simulation in information systems research to be discussed involves a set of information economics studies. As will be seen, this research permitted one to estimate both the value of differences in the timeliness of information and the value of an information system based upon the management control process of budget feedback.

When these particular studies were initiated*, the conceptual foundation of information economics had been developed by Marshak [3] and others, but little had been done in terms of empirically or pragmatically testing information value notions. Part of the difficulty in applying these notions lay in the complex decision processes within which extant information systems derive their value and part lay in the lack of methodology in which to analyze information systems differences. In the studies to be described, simulation and gaming techniques proved to be the key to resolving such difficulties.

SPECIFIC RESEARCH OBJECTIVES

The specific research focus is founded upon the perspective of the information system designer. From this point of view, a decision problem may be formulated which involves selection of an information system I^* which optimizes the net utility for the entity of interest. In information

---

*Mock [4]

economics, this design problem is developed in terms of basic decision theory and is seen to rely upon:

1. a decision maker,
2. a set of relevant states-of-the-world,
3. the decision maker's prior expectations concerning such states,
4. a set of feasible decision alternatives, and
5. a utility or payoff function defined on the possible outcomes which are a function of the alternative chosen and the state-of-the-world which occurs.

Within such a model, the role of information is to alter the decision maker's prior expectations such that chosen alternatives can be conditional upon the world-states that occur or upon the "real" prior probabilities.

Based upon the above decision theoretic view of analyzing information systems, but conditioned with the knowledge that pragmatic decision making is based upon more complex behavioral foundations, a set of business game experiments were designed to consider:

1. The predictive validity of estimates of information value based upon information economics.
2. The usefulness of gaming and simulation as a methodology for empirical estimation of cost and value of information.
3. The role of behavioral and pragmatic complexity factors such as learning and decision approach in information systems analysis.

In addition, discreet-event simulation was found to be a useful analytical methodology for the estimation of information values in a complex but well-defined decision model.

THE UNDERLYING MODEL AND INFORMATION DIFFERENCES TESTED

In order to investigate two sets of alternative information systems, a business game was developed, validated, optimized and implemented at three different universities. The actual implementations are summarized in Exhibit 1 which contrasts the information differences tested and technical implementation features. As is evident in this exhibit, two distinct experiments were conducted. The first experiments permitted subjects to reach decisions based upon real-time information (Information System I_1) or one-period lagged information (Information System I_2) about relevant environmental parameters such as input costs and external demand. A second set of business games (conducted both at UCLA and Ohio State University) were based upon two different information Systems — a budget variance system (Information System I_3) and a system based upon conventional income statement feedback. A common decision model and set of environment parameters was the basis for all experiments. Its mathematical structure is as follows:

Maximize: $\Pi_t = P_t Q_t - C_t$

Subject to: $P_t = \beta_t - .03\, Q_t + 95\, A_t - A_t^2$ (1)

$C_t = \alpha_t + c_t\, (.0075\, Q_t^2 - .075\, Q_t) + 5000\, A_t$ (2)

$1 = 2\, (M_t L_t)^{1/2}$ (3)

$c_t = P_{Lt} L_t + P_{Mt} M_t$ (4)

$M_t,\ L_t > 0$ (5)

$Q_t \geq 10$ (6)

$0 \leq A < 75$ (7)

α_t, β_t, P_{Lt}, and P_{Mt} are stochastic parameters which were fixed for each t and greater than 0, where for each period t:

Π_t = profit

P_t = selling price

Q_t = quantity produced and sold*

C_t = total cost

A_t = advertising units purchased*

M_t = material input*

L_t = labor input

c_t = input cost per standard unit produced

P_{Mt} = cost of materials

P_{Lt} = cost of labor

---

*Decision variables

EXHIBIT 1

Summary of the Three Experiments Conducted

University Site	Information Differences	Decision Variables	Simulation Environment
I. U.C., Berkeley	Timing: Real-Time Versus Lagged (I_1 vs. I_2)	Production Quantity Production Inputs	Management Science Laboratory, Individual Cubicles, Teletype Interface with PDP 5/8 Specialized, ECL Language
II. U.C.L.A. and	Feedback: Formalized Budget Variance Feedback vs. Traditional Income Measures (I_3 vs. I_4)	Production Quantity Production Inputs, Marketing Effort	Individual Cubicles, 2741 Interface, APL Language
Ohio State	"	"	Individual Cubicles, 2741 Interface, CPS Language under TSO

Maximize: $\Pi_t = P_t Q_t - C_t$

Subject to: $P_t = \beta_t - .03\, Q_t + 95\, A_t - A_t^2$ (1)

$$C_t = \alpha_t + c_t\, (.0075\, Q_t^2 - .075\, Q_t) + 5000\, A_t \quad (2)$$

$$1 = 2\, (M_t L_t)^{1/2} \quad (3)$$

$$c_t = P_{Lt} L_t + P_{Mt} M_t \quad (4)$$

$$M_t,\ L_t > 0 \quad (5)$$

$$Q_t \geq 10 \quad (6)$$

$$0 \leq A < 75 \quad (7)$$

α_t, β_t, P_{Lt}, and P_{Mt} are stochastic parameters which were fixed for each t and greater than 0, where for each period t:

Π_t = profit

P_t = selling price

Q_t = quantity produced and sold*

C_t = total cost

A_t = advertising units purchased*

M_t = material input*

L_t = labor input

c_t = input cost per standard unit produced

P_{Mt} = cost of materials

P_{Lt} = cost of labor

---

*Decision variables

This model was communicated to each subject by means of a scenario. Essentially the decision maker faced a series of decisions of selecting Q, A, and M each period depending upon the (expected) state of uncontrollable environmental parameters (P_L, P_M and β being relevant to the decision maker). Values of these parameters were generated as random walks and were the same for each experimental subject.

MODEL OPTIMIZATION

The above decision model is based upon a homothetic production function so that theoretically the system may be optimized by first minimizing period input cost and then, using the derived inputs, maximizing profits. The cost minimizing material input is

$$M_t^* = .5(P_{Lt}/P_{Mt})^{1/2}$$

Labor input is then uniquely determined given equation (3).

Profit maximization results in the first order conditions:

$$0 = \beta_t - .06Q_t + 95A_t - A_t^2 + .075c^* - .015c^*Q_t$$

$$0 = 95Q_t - 2A_tQ_t - 5000$$

where c* = minimum unit input cost.

A proper selection of parameters according to second order conditions and according to the constraints of the decision model insure that a unique solution exists for each decision period.

One will note that optimization of such a system is dependent upon a number of important decision maker assumptions and upon available information concerning input costs (P_{Lt}, P_{Mt}) and the demand index β_t. Under the first information system I_1, subjects received real-time information concerning these parameters, and thus they could have conceivably reached overall optimal decisions. Under information system I_2, messages concerning these parameters were lagged one period, thus expected profits was less. The differences in expected profits which may be derived from information economics notions, is then hypothesized as the <u>expected value of the more timely information</u>.

Derivation

DEVIATION OF THE EXPECTED VALUE OF INFORMATION; AN ANALYTICAL AND A SIMULATION APPROACH

Within the above decision problem two notions of information value are evident. First, one might ask what is the expected value of I_1 over I_2 given the actual set of environmental conditions that existed in the 15 periods for the experiment. Let us call this the <u>ex post value of information</u> as it can be calculated only after actual parameters are known.

Second, one might ask what the value of more timely information would be at the beginning of the experiments (t=o). At this point the decision maker is facing a very large number of possible environments as each of the four parameters may take on a large number of values dictated by a random walk process for each of the 15 decision periods. The value of information for this problem is known as the <u>ex ante value of information</u>.

The former information value (ex post) may be calculated using straight analytical techniques and is given in Table 1.

TABLE 1

The (ex post) Value of Information Structure I_1 (real time) Compared to I_2 (lagged information)

Period	Optimal Attainable Profits Given I_1	Optimal Attainable Profits Given I_2	Difference (Value of I_1 over I_2)
1	146279	146244	35
2	149026	149003	23
3	166695	166695	0
4	204102	201636	2466
5	229461	229301	160
6	237119	234260	2859
7	213661	212415	1246
8	208328	208063	265
9	179113	178974	139
10	252329	246907	5422
11	305518	300083	5435
12	351448	350006	1442
13	270056	268305	1751
14	304562	301353	3209
15	299706	298973	733
	Total		25,185
	Average periods 1-15		1,592
	Average periods 4-15		2,094

In the actual experiments, realized profit differences were obtained and contrasted to those that were theoretically attainable [$2,094 average per period for periods 4 to 15. Note that periods 1 to 3 were set aside for learning purposes.].

The estimation of the <u>ex ante</u> value of information turned out to be a much more difficult analytical problem and indeed a problem that was a prime prospect for simulation techniques. To our knowledge, this represents one of the few applications of simulation to an information economics question.

A SIMULATION STUDY OF THE 15 PERIOD MODEL

Using APL/360, a simulation model of the above decision problem was programmed and validated. The simulation itself utilized variance reduction techniques and consisted of two basic modules.

1. Random variates, antithetic and correlated, were generated for the 15 periods for each environmental parameter.
2. A decision module conditioned on available information (I_1 or I_2) generated optimal decisions which resulted in profits attained and estimates of information value.

BASIC RESULTS -

The simulator was run many times - 15 periods each - for both types of information structures -- real-time and lagged time. Based upon the average profits for each 15 period run, standard deviations were calculated. The results for one 40 run sample which were validated by other runs are summarized as follows:

	Mean Profit	Standard Deviation of Average Profits
Real-Time (I_1)	$180,320	$28,118
Lagged-Time (I_2)	175,514	27,785
Difference	3,706	912

According to these results, the ex ante profit differential due to the real-time system is $3,706 per period. Before a decision maker or the system designer would be willing to invest that amount, the distribution of values around the expected value should be examined. The value of the real-time information system is clearly positive since all values are greater than zero. But the standard deviation is $912 giving some indication of the amount of risk.

Note that the mean ex ante information value exceeds the so called ex post value. Thus a "rational" (expected value maximizer) decision maker could have paid more for real time information at the beginning of the business game than it turned out to be worth. Clearly, the actual experimental environment was less variable than one would expect given the underlying distributions of stochastic parameters. Before closing this section, it should be noted that the simulation approach solved a problem that was virtually impossible to attack analytically, an approach which proved unfruitful for over three years. The main reason why simulation was an appropriate methodology for estimating ex ante information value was that it leads itself to quantifying the underlying decision, payoff, information and environmental functions within a stochastic analysis.

OVERALL GAMING RESULTS

Given the preceeding estimates of information value and the underlying economic game, the two sets of information alternatives (I_1 vs. I_2 and I_3 vs. I_4) were implemented. Although the experiments resulted in data which contributed evidence concerning a number of information-decision process variables, such as learning patterns and decision approach effects, this paper focuses upon insights gained with respect to information systems questions.*

THE EXPERIMENTAL VALUE OF INFORMATION : TIMING DIFFERENCES (I_1 versus I_2)

The initial set of experiments utilized a real-time versus a one-period lagged information system as the experimental treatment. In these games, 72 subjects including 25 full-time businessmen participated in 15 decision periods where the first three were utilized as "learning periods." In Table 2, the basic results of these experiments are given. In addition these data are plotted in Exhibit 1 so that one may observe the basic patterns of the results. Observe that actual profit differences were in the directions predicted (e.g., the more timely information was functional to improved decision maker performance) but that such differences are significantly larger than expected (both of these differences are statistically significant). It is also evident that decision makers were unable to realize optimal profits (Exhibit 1, Part C) and that little learning occured after decision period 3. Subsequent analysis of the data* showed that behavioral factors such as decision approach and learning did not explain variations in observed profits but that the amount of time utilized by I_1 and I_2 subjects was significantly different. Thus one is uncertain to what extent the more timely information (I_1) or the additional decision time spent resulted in the excess profits realized by I_1 subjects.

*For a more complete exposition of behavioral and other considerations see Mock [5 & 7] and Mock, Estrin and Vasarhelyi. [6]

TABLE 2

Average Profits and Profit Differences Realized
for I_1 and I_2 Decision Makers

Average Profits

	I_1 Subjects		I_2 Subjects			
Period	Dollars	Percent of Optimal	Dollars	Percent of Optimal	Actual Profit Difference	Theoretical Profit Difference
1	60737.	0.415	51624.	0.353	9113.	35.
2	-279752.	-1.877	28860.	0.194	-308612.	23.
3	100863.	0.605	73507.	0.441	27356.	0.
4	145534.	0.713	143771.	0.713	1763.	2466.
5	159779.	0.696	115517.	0.504	44262.	160.
6	177607.	0.749	150001.	0.640	27606.	2859.
7	120892.	0.566	143935.	0.678	-23043.	1246.
8	112156.	0.538	139838.	0.672	-27682.	265.
9	116036.	0.648	101359.	0.566	14677.	139.
10	189072.	0.749	178467.	0.723	10605.	5422.
11	224626.	0.734	186593.	0.622	37669.	5435.
12	246165.	0.700	213304.	0.609	32861.	1442.
13	171862.	0.636	159742.	0.595	12120.	1751.
14	196641.	0.646	192458.	0.639	4183.	3209.
15	199739.	0.666	193914.	0.649	5825.	733.

EXHIBIT 1

Plots of Average Profits (A), Profit Differences (B), and Relative Profits (C) (Actual divided by optimal) for I_1 and I_2 Decision Makers

A. Average Profits I_1 Subjects o

Average Profits I_2 Subjects *

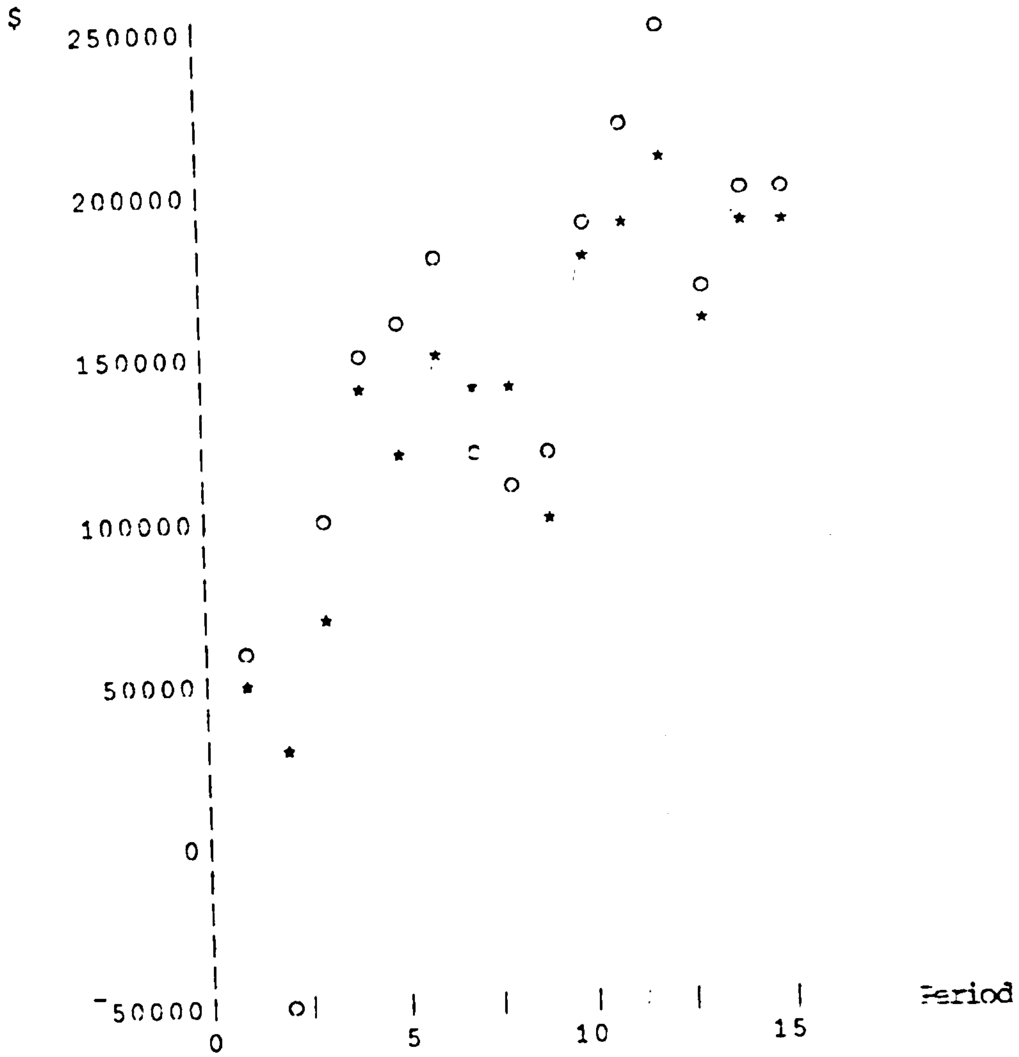
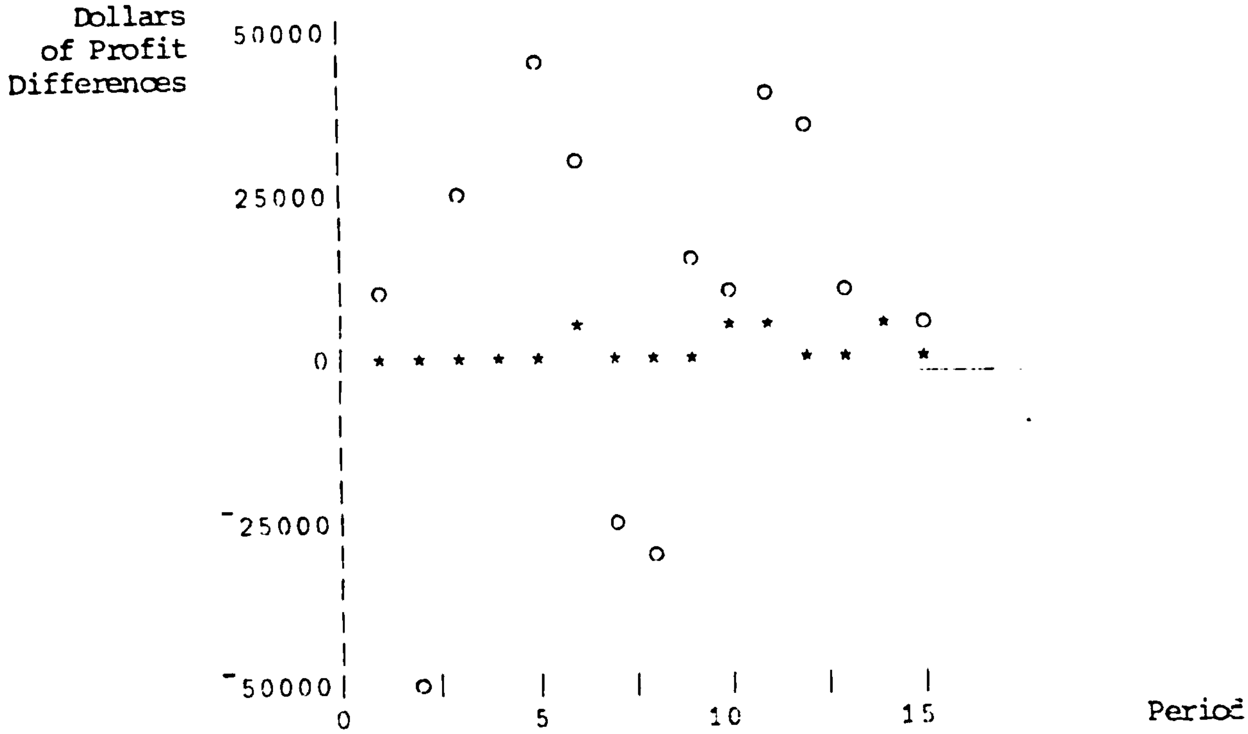


EXHIBIT I

B. Actual Profit Differences o

Hypothetical Profit Differences *



C. Relative Profits I_1 Subjects o

Relative Profits I_2 Subjects *

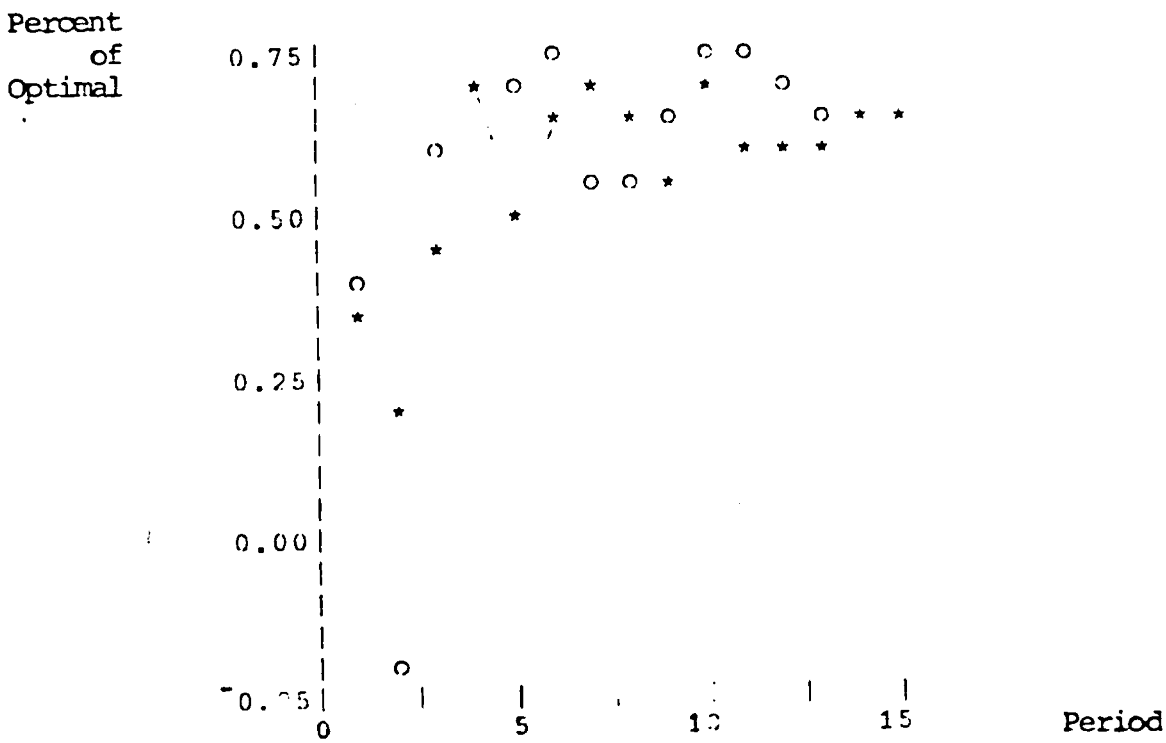


EXHIBIT 2

Plots of Profit Differences (A) and Relative (Realized Profits divided by Optimal) Profits (B) of I_3 and I_4 Decision Makers

A. Difference in Realized Profits for I_3 - I_4 Subjects

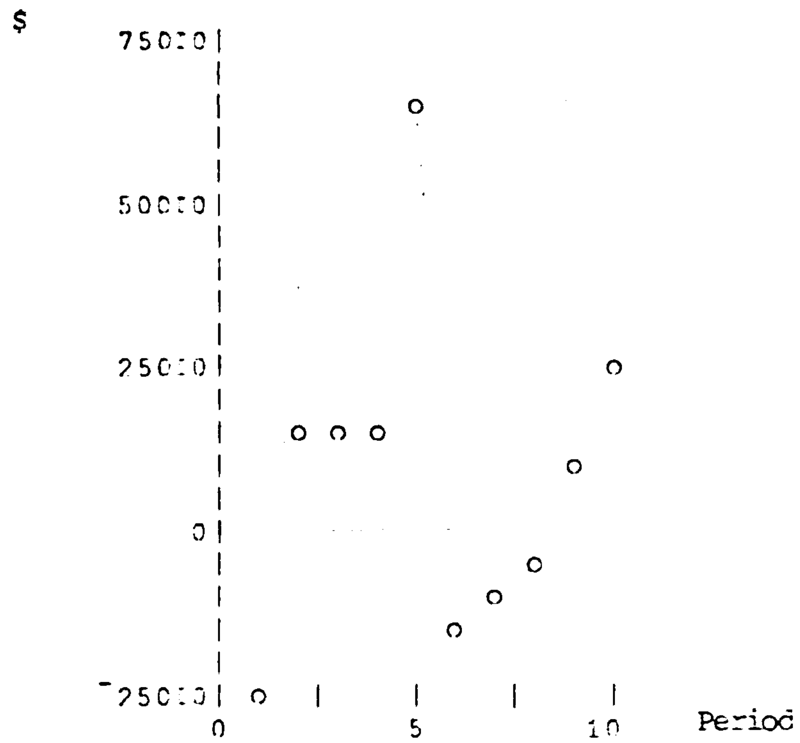
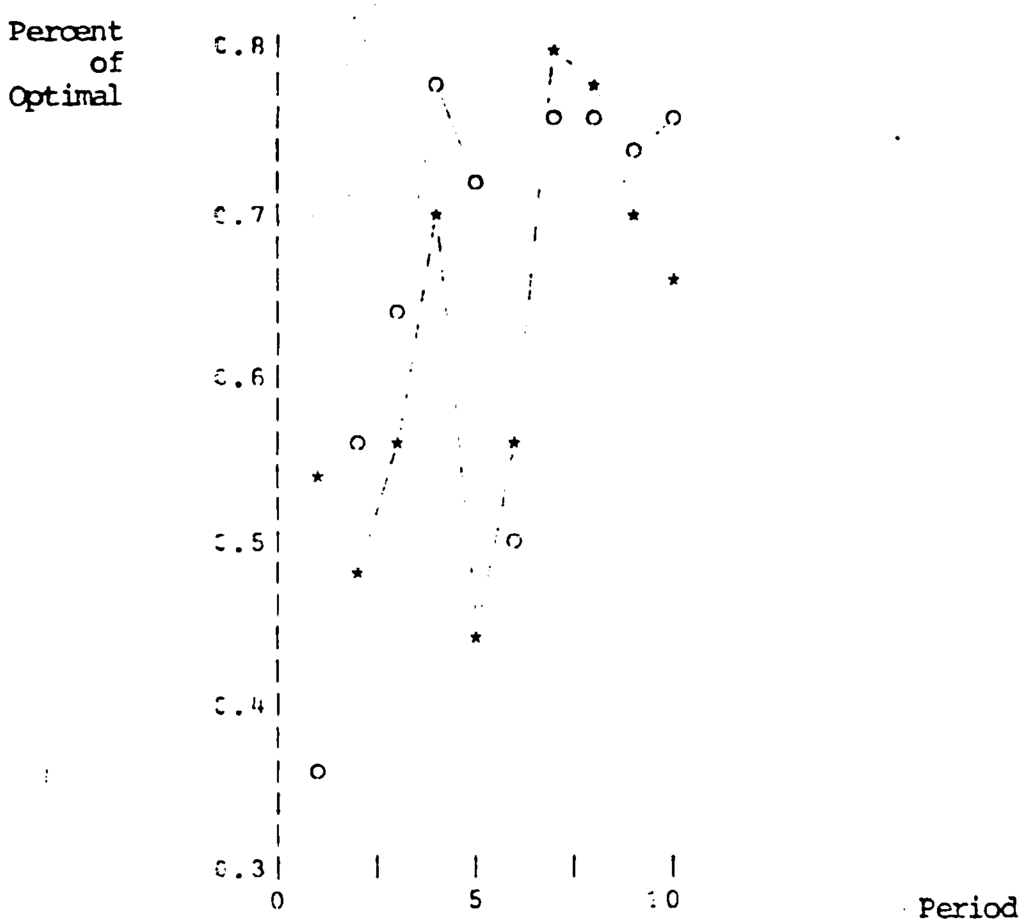


EXHIBIT 2

B. Relative Profits Earned I_3 Subjects o

Relative Profits Earned I_4 Subjects *



An examination of these data indicate that budgetary feedback information was functional to improved decision maker performance to the tune of $12,520 per period for periods 2 to 10.*

An examination of the learning curves for both subject groups indicates that learning was evident for both groups. Yet rates of learning were not significantly different, although I_3 subjects exhibited the higher rate. A complete analysis of variance of the experiments indicated that information system, motivation, learning and individual differences each accounted for the observed variance in the experimental data.

As the overall preceeding evidence indicates, if one considers available methodologies for information system research, simulation and gaming are among the most useful and feasible methodologies. Such experiments exhibit the necessary degree of internal control to permit statistical inference and a realistic degree of external validity. Most subjects found the experiments interesting and evidence points towards sufficient motivation and effort.

In the following section, the reader will find an even more complex and realistic use of simulation in information systems research. In these studies, experimental control is relaxed in order to investigate a series of information and decision maker variables within the context of a strategic planning problem which is aided by an online directive planning system.

---

*The second experiments were conducted for only 10 periods. Period one is not considered as feedback occurs only after period one.

SIMULATION OF PLANNING SYSTEMS*

Objectives and Problem Relevance

Thus far the studies considered have concentrated on the reactions of decision makers to different information structures. Also of importance is the entire communication system, including the problem of man-machine interaction.

The study of complex management systems involving men and machines in symbiotic interaction requires complex methodologies. For example, real-life observation of events often fails to discriminate between events and their causes due to the complexity of the environment. Therefore a study which has a main objective of examining the behavior of managers in man-machine interaction requires a more controlled laboratory or gaming environment. Such an environment would increase control but should not become trivial or deterministic in nature.

The quest for validity of a surrogate environment (and system) in forthcoming management information systems requires online characteristics and a relevant management problem such as planning. Therefore the dual objectives of behavioral and information systems research led to a philosophy of information systems design as suggested by Vasarhelyi [10]. This section of the paper examines the utilization of simulation and gaming for the above objectives.

*See Vasarhelyi [11].

Simulation in this case is not used as a closed system but as an environment for man-machine interaction.

MODEL DESCRIPTION

As too little is known about basic man-machine interaction factors, within an online planning environment, this study focused on three main areas; behavioral factors (decision approach, information utilization and decision speed), man-machine utilization factors (affinity for computers, "power", flexibility, difficulty with...) and secondary factors (sex and recruitment).

The Simulation Model

In order to examine these three areas, a simulated environment was created with a history and a problem situation described in a case. A decision tool was also provided in the form of an interactive planning system with an inbuilt database which contained the firm's history. This decision tool, which in essence was a directive Interactive Planning Simulator (IPS), led the user (manager) through a sequence of planning steps:

1. Objective setting
2. Problem formulation
3. Alternative generation
4. Alternative evaluation
5. Alternative choice
6. Feedback

Steps 1 to 3 provided the user with direction in his planning process while step 4 provided O.R. and simulation aids for decision making. Step 4 involved financial ratio calculations of financial statements and a financial planning simulation for the firm. This simulation allowed the decision maker to examine the expected impact of his actions (e.g., issuing bonds or factoring accounts to provide cash) and policy changes (e.g., increase the cash/accounts receivable ratio, decrease the level of borrowing) throughout the planning process of the simulated enterprise. Therefore the overall organizational simulation of man-machine interaction also included a financial simulation module. Such a simulation within a simulation game facilitated the measurement of the man's reaction towards the modeling of financial systems as well as the overall research objectives of measuring the individual's behavior.

IMPLEMENTATION FEATURES

Language Selection

APL was clearly the language to be used as it was the most powerful language available and its conversational features were especially useful for man-machine interaction. Its major shortcoming — limited workspace size — was bypassed when STSC Plusfile was made available. This facilitated access to files larger than the basic APL workspaces. Also as the nature of this research was mainly developmental with a small production/development ratio, the interpretative nature of the language was not a significant drawback in terms of cost.

The results of the research indicate that analytic decision makers should have systems tailored to:

1. Emphasize quantitative data
2. Permit ease of usage

Yet rapid response time was less important for such subjects. On the other hand, heuristic decision makers require systems which

1. Emphasize qualitative data
2. Are flexible in nature
3. Facilitate rapid interaction

Finally, analysis of attitude changes indicates that interaction with a system such as the IPS will improve users' attitude towards computers both for experienced and inexperienced computer users.

<u>Findings in the Pre-Implementation Testing of Software Systems</u>

In addition to the behavioral findings mentioned above this study added further evidence as to the functionality of simulation as a tool for long-scale software systems development. During the design phases, major problems within the simulation were discovered. These findings could easily be generalized to a real-life software development project. The programming phase identified a series of factors that in a simulation situation are easy to correct but are very serious in nature if they occur in a real life development. For example, in the original IPS, files had not been dimensioned adequately. Thus trace matrixes became too large and resulted in "WS Full" errors during execution. A segmenting routine easily corrected this problem.

Most of all the experimental part led to user preferences, feedback and performance under simulated conditions. Such evidence would undoubtedly lower overall development costs in large-scale software systems while producing a more adequate system from the user's standpoint.

For example, upon examining user feedback it became clear that the need of making a very clear dialogue with the user was necessary. However, redundant instructions made the system too verbose and repetitive for the user after some utilization. A real life implementation could benefit from this experience and provide different levels of dialogue for the different stages of system utilization.

Overall Results and Implications

This paper has emphasized the use of simulation and gaming in information systems research. In contrast, the preponderence of traditional research in this field is pragmatic knowledge, field studies, and theoretical studies such as decision theory. The main obstacle to basic research in this field is the complexity of the variable inter-relationships and the number of factors involved in large systems. The two main sections of this paper discussed studies which deal with these problems by using a laboratory approach with simulation and gaming. These studies relied on similar approaches and dealt with key factors in information systems research. The first set of information-decision process studies dealt with information economics, while the second with information utilization and behavioral factors in information systems. Figure IV.1 compares the two experiments with respect to overall features. Both experiments were performed in simulated environments using surrogate populations. These populations were carefully observed and timed as they performed a well-defined task. This task led to quantitative decision in the first experiment and quantitative-based decisions in the second. The analysis of results led to similar conclusions concerning manager's decision styles, where in all experiments the heuristic/analytic decision approach (cognitive style) framework was shown to be discriminative. This implied that advantages could be obtained by tailoring information systems to the behavioral characteristics of decision makers. Findings related to ways of supplying information, desirable characteristics for man-machine decision makers and others were also obtained. Each of these is possibly another step towards the comprehension of information. Much is still to be accomplished especially in the study of the interrelations between basic variables. Such a comprehension only can be reached through the laboratory approach and the utilization of simulation and gaming!

The utilization of simulation in information systems research requires a different emphasis than normal discrete-event simulation studies. Verisimilitude, control and sequential dependence must be emphasized instead of traditional simulation criteria such as representativeness, stochastic validity and structural analogy. Barton [1, p. 58] defines "verisimilitude, which means that, while simulation is obviously an artificial representation, it has the quality of being true to life or to human experience." Control,

FIGURE IV.I

COMPARATIVE TABLE

Feature	Information Economics Study	Behavioral Planning Study
Language Implemented	APL, CPS	APL
Number of Subjects	112	50
Location of Studies	Berkeley, UCLA Ohio State	UCLA
Emphasis	1. Information Structure 2. Value of Information 3. Decision Approach	1. User attitudes 2. Information Utilization 3. Decision Approach 4. User background
Number of APL Workspaces	3	4
Time Spent per Subject	2 - 3 hours	2 - 6 hours
Method of Evaluation of performance	Comparison with Optimal Values	Judge Rating
User Response Timing	Automatic	Automatic
Nature of Subjects	Managers and Graduate Students	Managers and Graduate Students

BIBLIOGRAPHY

1. Richard F. Barton, A Primer on Simulation and Gaming, Prentice-Hall, Englewood Cliffs, 1970.

2. Fred N. Kerlinger, Foundations of Behavioral Research, New York: Holt, Rinehart and Winston, 1966.

3. J. Marschak, "Economics Theory of Information," Working Paper 118, Western Management Science Institute, University of California, Los Angeles (May, 1967).

4. T. J. Mock, The Evaluation of Alternative Information Structures, unpublished Ph.D. Dissertation, University of California, Berkeley (1969).

5. T. J. Mock, "Comparative Values of Information Structures," Journal of Accounting Research (1969 Supplement, pp. 124-129).

6. T. J. Mock, T. L. Estrin, and M. A. Vasarhelyi, "Learning Patterns, Decision Approach and Value of Information," Journal of Accounting Research (Spring, 1972, pp. 129-153).

7. T. J. Mock, "The Value of Budget Information," The Accounting Review (July, 1973).

8. C. E. Osgood and G. G. Suci, "Factor Analysis of Meaning," Journal of Experimental Psychology, 1955, pp. 325-338.

9. S. Siegel, Nonparametric Statistics, New York, Wiley, 1956.

10. M. A. Vasarhelyi, "Simulation: A Tool for Design and Pre-Implementation Testing of Large Scale Software Systems," Proceedings of the Winter Simulation Conference, 1971.

11. M. A. Vasarhelyi, Man-Machine Planning Systems: A Behavioral Examination of Interactive Decision Making, Unpublished Ph.D. Dissertation, University of California, Los Angeles, 1973.