THE USE OF SYSTEM DYNAMICS TO MEASURE THE VALUE OF INFORMATION IN THE BUSINESS FIRM

Fred K. Augustine, Jr.
Department of Accounting and Information Systems
School of Business Administration
Stetson University
DeLand, FL 32720

Thomas D. Clark, Jr.
Department of Information and Management Science
College of Business
Florida State University
Tallahassee, FL 32306

ABSTRACT

The primary focus of the research reported in this paper was on the measurement of the value of information in the business firm. It involved development of a system dynamics model of a typical business firm and calibration of the model to an average firm in the can industry in the United States. The model has the five sectors of marketing, finance, production, research and development, and personnel. Data to calibrate the model came primarily from the Industrial Compustat data base. The model was used to test several propositions about the economic value of management information. This topic has been addressed by Morecroft (1977, 1979), Jones (1981) and others. The research extends work by them as well as demonstrating the multidimensional nature of information using the Gorry and Scott-Morton framework of typical information structure. A framework in which to assess information value is developed and discussed.

The performance of the firm was assessed using cost, profitability and efficiency measures under various values for the information attributes of accuracy, timeliness, relevance, and reliability at the strategic, managerial and operational levels of the firm. Several propositions about information value are offered given the results of the testing.
(Key Words: Information Value, System Dynamics, Business Analysis, System Performance)

INTRODUCTION

Like other vital resources, information must be managed to insure that its cost is compensated for by the benefits which accrue to the organization by virtue of its possession. Since information systems are the tools used in the "acquisition, use, retention and transmission of information," (Weiner, 1948) these resources must be managed in the same way as the material, financial and personnel resources which the organization controls. In order to accomplish this, resource managers must have a means of measuring both the cost and the benefits which an information system provides.

In practice it has been much more difficult to measure the benefits of an information system than to quantify its costs. Information itself provides value to an organization. Information resource managers have recognized this fact by implementing systems which attempt to maximize the value of the information provided. The value of information, has proven to be extremely difficult to quantify and since the benefits to an organization of an information system are defined by the information which it provides to decision makers, it is the quality of this information which must be measured in any cost/benefit analysis.

Approaches to Establishing Value

A number of techniques have been proposed for evaluating the quality of information. Four major approaches to information valuation have been identified and are discussed below. One of the earliest approaches to assessing the value or quality of information was the information economics approach. This approach employs statistical decision theory to determine the incremental cost of information which can be compared with a specific set of benefits. The assessment of benefit is usually approached using the utility preference of a single decision maker, a set of available alternatives, a set of possible system states (outcomes), and alternative information patterns, all of which must be a priori known. Although theoretically appealing, the rigid assumptions of this approach limit its applicability with respect to the complex, dynamic environments which exist in organizations (Zmud, 1978).

Since user satisfaction has been widely used as a measure of information systems success (or failure), it follows that it should also be an appropriate measure of system benefits. The perceived or utility value approach uses a similar method by soliciting the attitudes of the user about an information system. This technique is highly subjective in nature and suffers from the limitations of techniques which attempt to assign numeric values to entities (such as attitudes) which cannot be directly measured.

The economic value approach utilizes a somewhat similar method. Information system users are asked to appraise the monetary value of the information provided by the system. This method suffers from the difficulty which exists in assigning meaningful dollar values to system attributes which are essentially intangible and from differences in the perception of appropriate dollar values for the same information by different users (Zmud, 1978).

A systems approach to assessing the value of information systems has been proposed (Swanson, 1971; Morecroft, 1979; Jones, 1981). This approach utilizes simulation modeling in an attempt to overcome the limitations of the valuation methods previously discussed. The simulation modeling approach attempts to assess the benefits of information by examining the relative merit of a set of information attribute values in terms of their impact on overall system performance. To do this a relevant set of attributes must be identified and different dimensions (or levels) of the attributes must be assigned and the performance of the system measured. The benefit of any performance gain must then be related to the cost of providing the information to establish economic value. The application of this experimental approach assumes the existence of a valid simulation model. This model must effectively incorporate the decision and information processing structures of the organization of interest.

Use of System Dynamics In Establishing Information Value

The overall quality of information can be expressed in terms of the attributes which define its dimensions. These dimensions can be described in terms of the properties which define the nature of information. Any information will, indeed, have some set of attributes that determine its usefulness for a given decision process. Its value, therefore, is an evaluation (either formal or informal) of information along one or more of its dimensions. The literature addressing this topic is limited, especially with respect to empirical research aimed at a determination of a set of these attributes which adequately describes the concept of information. One notable exception is a study by Zmud designed to empirically determine the attributes which describe the of concept information in terms of its dimensions. As a result of the analysis, an eight factor structure was accepted as providing the derived dimensions of information. The eight derived dimensions of information formed four classes of information: (1) overall quality, (2) a relevancy measure, (3) a measure of presentation quality, and (4) the quality of the meaning conveyed by the information.

The value or quality of information is related to its usefulness after its evaluation along one or a set of these attributes (Feltham, 1972; Marder, 1979). Quantification of these elements in the ratio or even interval scales of measurement is difficult, if not impossible, although surrogate measures can often be established. What must be done, then, to establish the information's value beyond a single decision maker is to assess its impact on overall system performance using some set of these attributes. To do this different levels of the attributes must be assigned and system performance measured. Thus, the value of information may be determined by measuring differences in the performance of decision makers when provided with information sets in which the specific values of these attributes are different. The benefit of any performance gain may then be related to the cost of providing the information to establish economic value.

The use of system dynamics in this context is particularly appropriate since "it lends itself to portraying the breadth of organizational structure encompassing several interrelated functional areas" (Morecroft, 1983). A major limitation of the information economics, utility value, and economic value approaches to information valuation has been the degree of abstraction and simplification of the information/decision environment which has been necessary to make valuation models manageable in terms of complexity and computational requirements. According to Forrester "such models will be far too complex (tens, hundreds, thousands of variables) to yield analytical solutions. In fact for nonlinear systems modern mathematics can achieve analytical solutions to only the most trivial of problems" (Forrester, 1961).

The systems dynamics approach allows for the incorporation within the model of the degree of complexity necessary to simulate system behavior. Thus, its use is especially applicable to the problem of information valuation. If the specific values of information attributes are to be related to overall system performance, any intervening variables or exogenous factors which could affect this performance must be either eliminated or controlled. A classical experimental design methodology which attempts to control for such factors would quickly become too complex for understanding or use. These factors can be incorporated into a system dynamics model and controlled to allow a more clear examination of the effect of information value on system performance. System dynamics offers a particularly rich environment for the simulation of industrial firms for the purposes of problem and policy analysis. Numerous examples of system dynamics models of industrial organizations can be cited (Swanson, 1971, Jones, 1981, Morecroft, 1983).

Research Focus and Model Structure

Decision making activities are the means by which management controls the flow and effective use of resources in pursuit of organizational objectives. Information about the status of organizational processes, resources, and capabilities along with a set of objectives for these entities are the essential inputs for managerial decision making. The outcomes of managerial decision making activities are dependent on the quality of the information provided by the organizational information system. As a result, there are negative consequences to the organization when there is a mismatch between decisions and the information

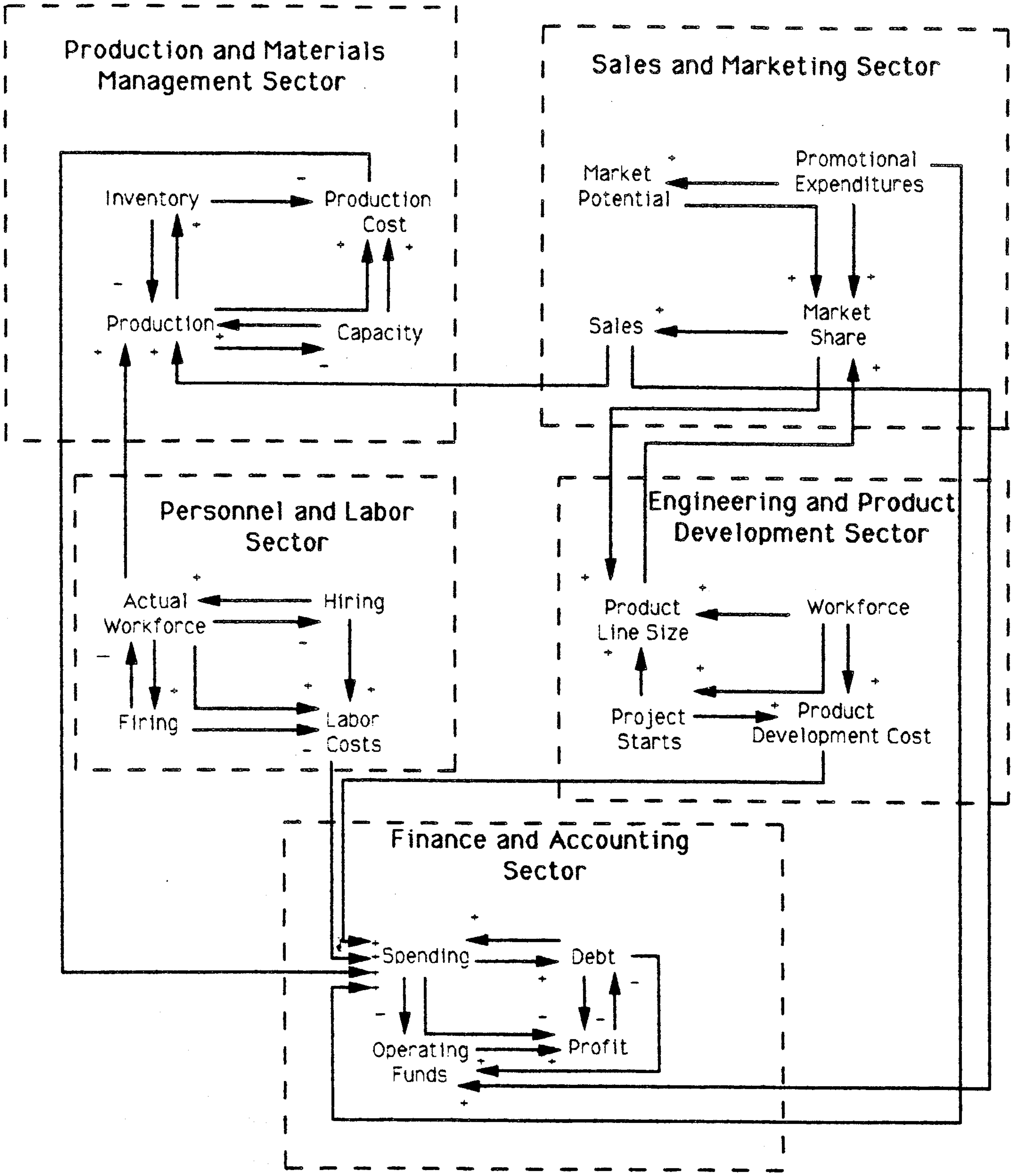


Figure 1. Sectors and Key Variables of the System Dynamics Model of a Manufacturing Firm.

Model Sector	Performance Measures	Literature Source
Finance and Accounting	Rate of Return .Return on Equity .Return on Investment	Price, Kilmann and Herden, Campbell
	Profitability .Net Income .Profit Margin	Price, Reimann
Sales and Marketing	Sales	Reimann Bonini, Negandhi and Reimann Sloma
	Market Share	Kilmann and Herden
	Demand Forecast Effectiveness	Sloma
Production and Materials Management	Production Capacity Utilization	Sloma
and	Output	Kilmann Herden, Sloma
	Inventory .Levels .Costs	Kilmann and Herden, Sloma, Bonini
Engineering and Product Development	Product Development Costs	Kilmann and Herden, Sloma
Personnel and Labor	Human Resource Retention .Employee Turnover	Kilmann and Herden, Negandhi and Reimann Sloma

Figure 2. Measures of Organizational Performance

used to support these decisions (Gorry and Scott-Morton, 1971).

Given the complex nature of organizations and their decision making structures, it is apparent that the outcomes of one decision may serve as inputs for a second decision, and those outputs may in turn provide inputs to the first decision making process in a subsequent iteration of the decision making activity. Thus the dynamic feedback nature of organizational decision making must be incorporated into the structure of any model which attempts to examine the effect of information quality on system performance.

The vehicle of study for this research is a dynamic model that incorporates the decision and information processing structures of a generalized manufacturing firm. The feedback structures of this model are illustrated using a causal diagram shown in Figure 1. This diagram depicts the causal relationships present in the major functional areas or sectors of a manufacturing firm. Certain assumptions were made about the model organization in order to reduce the complexity of the model without significantly decreasing its similarity to actual manufacturing firms. In addition, these assumptions were useful in further defining the type of industry and organization used as a basis for the model so that actual industry data could be used in developing and validating the model.

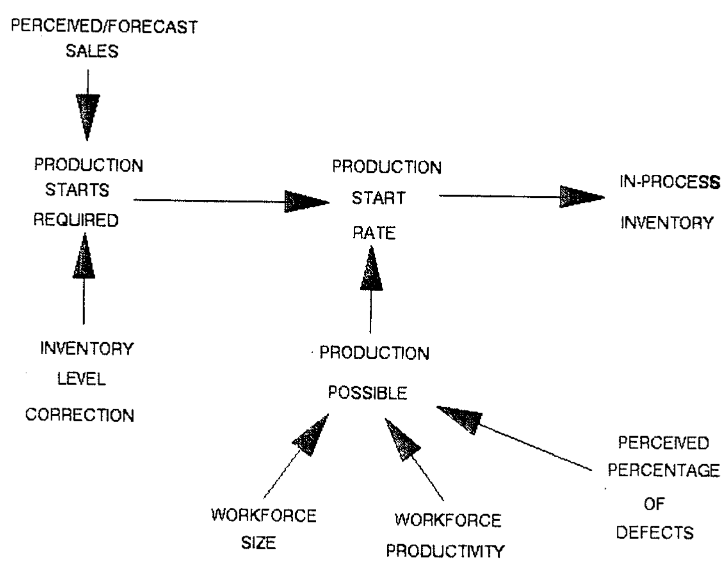
The use of this type of model for the purpose of organizational analysis is predicated on the development of systemic measures of organizational performance which will allow the evaluation of alternative decision rules and organizational policies. The structure of the manufacturing firm model and the multi-dimensional nature of organizations suggests that a single measure of organizational performance would be an inadequate means of describing the performance of such a system. The organizational effectiveness literature does not indicate the existence of any single systemic measure of performance. Indeed, there is no widely accepted set of specific performance measures (Steers, 1975). A valid alternative to a single systemic measure is to identify an acceptable set of organizational performance measures which represent a consensus of those proposed in the organizational effectiveness literature. A set of performance measures was used based on those which have been identified in the literature and are specifically relevant to manufacturing firms (Bonini, 1963; Price, 1968; Campbell, 1973; Kilmann and Herden, 1976; Sloma, 1980; Reimann, 1982). These performance measures are organized into three groups for the purpose of presenting the results of the experiments. The performance measure groupings (Figure 2) are for measures of profitability, cost, and efficiency of resource utilization.

The general structure of the manufacturing firm model which was outlined in the diagram in Figure 1 was converted to a more detailed model that was assigned parametric values and given mathematical structure. The manufacturing firm model used in this research is composed of five sectors corresponding to five functionally differentiated organizational sub-units (production, sales and marketing, personnel, finance, and product development) which are common to most manufacturing organizations. The functional form of organization structure is chosen since it is by far the most common basis for subdividing organizational activities.

In order to adequately address the subject of the effect of information value on the performance of the firm, the simulation model used must include structures which represent points in the organization where the process of management decision making is executed. The decision structures of the manufacturing firm model can be separated into two distinct groups. The decision making structures themselves (the variables which represent the results of a managerial decision), and decision information processing points (points in the model structure where information used at the decision making point is collected and/or processed).

Decision making takes place at all levels of an organization and for all activities in which an organization engages. Any study of the effects of the value of information used in decision making on system performance, must incorporate this concept. It is possible to classify organizational decision making activities as occurring at three organizational levels (Strategic Planning, Managerial Control, and Operational Control) corresponding to the type of management activity which necessitates the decision to be made (Anthony, 1965). Figure 3 is a flow diagram illustrating a specific decision making point in the model.

Figure 3
Decision Making Structure for Production Starts



Overview and Results

The experimentation performed using the manufacturing firm model consisted of a series of simulation runs in which the model structures representing four attributes of information (accuracy, relevance, reliability, and timeliness) were caused to vary. These information attributes were operationalized within the system dynamics model to allow for experimental variation in the values of those attributes. The information attributes of accuracy, timeliness, relevance, and reliability (as operationalized) were tested at three levels. The specific parameter values for these levels (Table 1) were suggested by previous research (Swanson, 1971; Kleijnen, 1980).

Table 1

Attribute	Operationalized	High	Level Medium	Low
Accuracy	Noise	1%	10%	20%
Timeliness	Input Delays	1	6.5	13
Relevance	Output Delays	1	6.5	13
Reliability	Sampling Interval	1	8.5	17

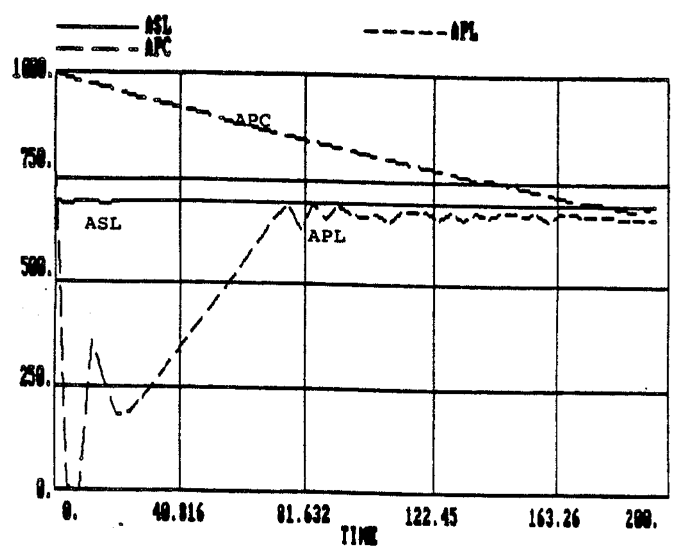
* All Delay times are in weeks

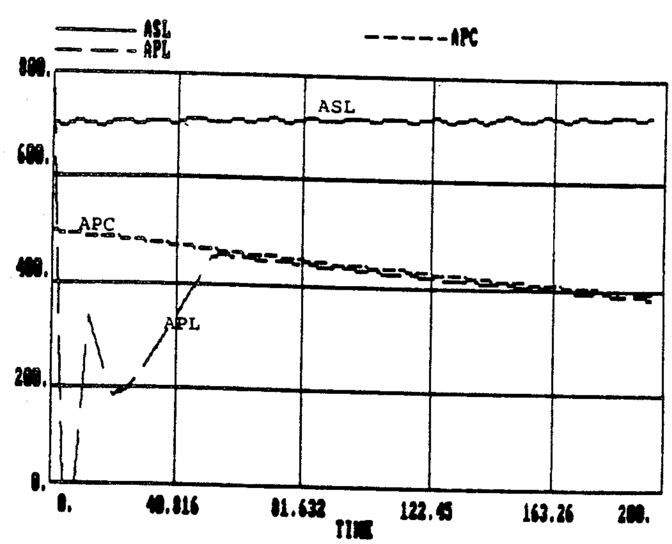
Based on the literature fifteen performance measures were selected for use in the experimental runs using the manufacturing firm model. These performance measures are operationalized in the form of DYNAMO supplementary equations. Thus, the equations which measure the performance of the simulated organization do not, in turn, affect that performance. A total of thirty-seven experimental simulation runs were performed testing differing levels of information value for each attribute and all three levels of managerial decision making. Each set of information value parameters was tested over a simulation period of 200 weeks (approximately four years). Figure 4 illustrates a simulation run depicting reference and test behavior for Sales, Production and Capacity.

As a result of this examination and analysis of the behavior of the model under differing levels of information values, it is apparent that the overall performance of the organization is affected by the value of the information used in decision making activities. Further, there is a differential effect depending on the information attribute and the level of decision making at which the information is used. In view of the results of the experimental simulation runs, certain general statements can be made concerning the effects of information value on organization performance. These statements represent working propositions based on the empirical evidence produced as a result of this research.

(1) Decreases in the value of information (expressed in terms of the accuracy, relevance, reliability and timeliness of that information) adversely affect the performance of the organization in terms of profitability, cost and efficiency of resource utilization.

Figure 4
Reference Behavior and Test Behavior for Capacity Cost = 10000
Initial Production Capacity = 500





(2) At each level of decision making, a decrease in the value information for a different information attribute appears to cause the greatest decrease in organization performance. Decreases in the value of information provided for decision making activities at the strategic level have the smallest overall effect on organizational performance, while decreases in the value of information provided for decision making activities at the operational level have the greatest overall effect on organizational performance.

(3) There exists a base or normal operating range for the value of information (in terms of its attributes) required by the organization for its decision making activities below which the performance of the organization is adversely affected and above which the marginal benefit of acquiring additional information is exceeded by its marginal cost.

(4) The requirements for information used in decision making in an organization are so diverse that no single attribute of information has a consistently greater or lesser effect on the performance of the organization when this performance is viewed in terms of each of the three performance measure groups.

(5) The greatest overall effect on performance due to the decrease in the value of information in terms of a specific information attribute, at a single level of decision making activity occurs as a result of a decreasing the reliability of information provided to operational level managers.

(6) The smallest overall effect on performance occurs for reductions in the timeliness of information used in strategic level decision making.

Implications of the Findings and Conclusions

The results of this study have general implications for the management of information resources. It has long been assumed that the implementation of a computer information system would provide benefits to the organization which would enhance the overall performance of the organization. Unfortunately, in most situations, management's ability to account for the cost of such systems has greatly exceeded its ability to quantify these benefits. This has become increasingly evident with the advent of management information systems and decision support systems that cannot be directly associated with personnel savings. Since these systems tend to be oriented toward supporting managerial decision making activities (as opposed to operative and clerical activities), the benefits of these systems have been less tangible.

Since information provided to decision makers in the organization is not provided without cost, and the cost of information provided by an information system tends to increase as its quality or value (measured in terms of its attributes) increases, any increase in the timeliness, accuracy, relevance or reliability of information produced by the system means an increase in cost. In addition to the cost of information, there is also a benefit assumed to an increase in quality or value of information used by the organizations decision makers. It is the nature of this relationship that is addressed by this research.

One very clear result of the experimental runs is that decreases in the value of information (beyond a base level) provided to decision makers can adversely affect the performance of the organization in terms of profitability, cost and efficiency of resource utilization. Each organization has a certain investment in information technology. Thus, management cannot afford to use an information system which provides information of a sub-standard quality or value to its decision makers.

These results, however, cannot be interpreted to imply that information of the highest possible value (and therefore cost) must be provided to decision makers at all levels of the organization. Indeed, the experimental results suggest that information of a lower value in terms of certain attributes can actually enhance performance at the strategic level of decision making, assuming that the organization's base or minimum information requirements for decision making have been met. A more appropriate strategy would be for an organization to continue its investment in providing higher levels of information quality for operational level managers and devote less resources to its strategic level information technology investment.

It has been suggested in the literature, that decision making activities at different levels of the organization require information of a different type and quality. This contention is supported empirically by the results of this research. In analyzing these results it is clear that management cannot apply the same standards for information (in terms of the value of its attributes) to the information system at different levels of the organization. Since increases in the value of information in terms of the values of its attributes increases the cost of that information, management must seek to provide information of an appropriate value to decision makers at each level of the organization.

These results also support the notion that organizations should design and implement integrated information systems which provide the appropriate levels of support at the level of the organization where it is required and using the level of technological and applications sophistication appropriate to each function provided. In light of these findings the use of system dynamics modeling to assist organizations in the evaluation of their information requirements would appear to be not only feasible, but of great potential benefit in the design, implementation, and continuing use of information systems.

REFERENCES

Anthony, R.N. "Planning and Control Systems: A Framework for Analysis." Cambridge: Harvard University, 1965.

Bonini, C.P. Simulation of Information and Decision Systems of the Firm. Englewood Cliffs: Prentice-Hall Publishing, 1962.

Campbell, J.P. "On the Nature of Organizational Effectiveness." In P.S. Goodman and J.M. Pennings (Eds.) New Perspectives on Organizational Effectiveness. San Francisco: Josey-Bass Publishing, 1977, pp. 13-35.

Feltham, G.A. "Information Evaluation." Studies in Accounting Research. Vol 5, American Accounting Association, 1972.

Forrester, J.W. Industrial Dynamics. Cambridge: The MIT Press, 1961.

Gorry G.A. and Scott-Morton, M.S. "A Framework for Management Information Systems." Sloan Management Review. Vol 13, No. 1, 1971, pp. 55-70.

Jones, J.W. "Application of a Performance Based Approach to Economic Valuation of Information." Journal of the Operational Research Society. Vol. 32, 1981, pp. 967-977.

Kilmann, R.H. and Herden, R.P. "Toward a Systematic Methodology for Evaluating the Impact of Interventions on Organizational Effectiveness." Academy of Management Review. Vol 1, No. 3, 1976, pp. 57-98.

Kleijnen, J.P.C. Computers and Profits: Quantifying Financial Benefits of Information. Reading: Addison-Wesley, 1980.

Marder, C. Information Systems: Technology, Economics, Applications, Management. Chicago: Service Research Associates, 1979.

Morecroft, J.D.W. "A Systems Perspective on Material Requirements Planning." Decision Sciences. Vol. 14, 1983, pp. 1-18.

__________. "An Integrated Approach to Industrial Dynamics." Alfred P. Sloan School of Management Working Paper. November, 1979, pp. 1-32.

Price, J. "The Study of Organizational Effectiveness." Sociological Quarterly. Vol. 13, 1972. pp. 3-15.

Reimann, B.C. "Organizational Competence as a Predictor of Long Run Survival and Growth." Academy of Management Journal. Vol. 25, No. 2, 1982. pp. 323-334.

Steers, R.M. "Problems in the Measurement of Organizational Effectiveness." Administrative Science Quarterly. Vol. 20, 1975. pp. 546-558.

Swanson, C.V. "Evaluating the quality of Management Information." Alfred P. Sloan School of Management Working Paper. June 1971. pp. 1-32.

Weiner, N. Cybernetics. New York: John Wiley and Sons, 1948.

Zmud, R.W. "An Empirical Investigation of the Dimensionality of the Concept of Information." Decision Sciences. Vol. 9, 1978. pp. 187-195.