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TOWARD A BEHAVIORAL THEORY OF INFORMATION VALUE

by

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WP 1191-81 February, 1981

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INTRODUCTION

There does not presently exist a model of the value of information in a realistic managerial setting. Surprisingly, there is very little effort in this direction, even though a successful model could profoundly affect our understanding of information support systems, organizational design, and managerial accounting.

Such a model would delineate the important variables that affect value. It would enable a prescriptive theory of design and organization of sources of information by providing a basis for valuing potential designs and configurations. It would apply to a broad class of information sources and allow meaningful comparisons between computer-based information support systems and groups of staff analysts working to supply information to busy line executives. The model would have to integrate important areas of economics, psychology, and decision theory to produce a realistic description of the managerial use of information.

In this paper, we set directions for the development of such a model. We start with a review of the efforts made in information economics to create a model of the value of information. The single source, single decision model is reviewed to illustrate the assumptions and techniques of this approach. Five major modifications of the models, suggested by descriptive theories of managerial behavior found in other fields of study, are discussed in turn. Finally, this entire approach is reviewed in a concluding section that indicates some general

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requirements of any plausible model of information value.

ECONOMICS MODELS OF INFORMATION VALUE

One branch of economics and another in statistical theory have been concerned with the value of information for more than twenty-five years.[Hirshleifer 1973] Operating as two distinct schools, information economics and statistical decision analysis have produced a series of similar models that value information in the context of several restrictive assumptions about the behavior, ability, and knowledge of actors using information. It is theory which describes information value only in the context of an economically rational, perfect actor, operating in a very restricted setting. L.J. Savage, the originator of the fundamental axioms upon which the information economics and decision analysis models are based, wrote that his was, "a highly idealized theory of the behavior of a 'rational' person with respect to decisions."[Savage 1954, p. 7]

Our concern is with the value of information to a real manager, with all his flaws and imperfections, acting in a more realistic, more complex environment. We are attempting to prescribe the variables that must be considered to produce a valid descriptive model of the value of information to a realistic manager. Such a model must be founded upon a realistic description of the managerial use of information, rather than upon the sterile, prescriptive assumptions of information economics and statistical decision analysis.

Next, we shall review one of the models of information economics as an illustration of the techniques and assumptions of that approach. Then we shall turn to a discussion of modifications of the information economics models that would make them more descriptive of managerial behavior and of the obtainable benefits of information.

The economics models of information value vary along two dimensions: the complexity of the information source and the number of decisions. The information source can be a single signal, a single information system, or multiple information systems and the decisions can be single or multiple. Figure 1 illustrates this diversity and indicates some references for each type of model.

	SINGLE SIGNAL	SINGLE INFORMATION SOURCE	MULTIPLE INFORMATION SOURCES
SINGLE DECISION	Marschak 1964 Raiffa 1970 Demski 1972	Raiffa and Schlaifer 1961 Marschak 1964 Mock 1971 Arrow 1972	
MULTIPLE DECISIONS		Schlaifer 1959 Feltham 1968 Marschak and Miyasawa 1968	Feltham 1972 Marschak 1968 Marschak 1971

FIGURE 1
ECONOMICS MODELS OF INFORMATION VALUE

We shall review here the single information system, single decision model of information value to give the flavor of this work and to illustrate the types of assumptions upon which it is founded. After this, we will illustrate the changes required to move to multiple source or multiple decision models.

Let us assume that we have a decision problem for which we are given:

- A finite set of possible actions, $A = \{a_1, a_2, ... a_J\}$, from which the decision maker must choose one action to complete the decision problem.

- A finite set of future states of nature, $S = \{s_1, s_2, ... s_I\}$, which are numerable, exhaustive with respect to the outcomes of actions, and mutually exclusive.

- A set of prior probabilities, $\{p(s_1), p(s_2), ... p(s_I)\}$ of each state of nature obtaining. They sum to 1.

- A stationary utility function, the value of which depends only upon the chosen action, a_j, and the state of nature that occurs, s_i. $U = u(s_i, a_j)$.

- An information source, N, which will produce one signal from $Y = \{y_1, y_2, ... y_K\}$, the set of possible signals.

- A matrix of probabilities of each signal occuring, given each state of nature. $\{p(y_k|s_i)\}$

The sequence of steps is then as follows. The information source produces one signal, y'_k. The decision maker uses the signal to calculate a revised probability, $p(s_i|y'_k)$ for each state of nature, s_i, which may obtain. An action, a'_j, is then chosen to maximize the expected value of the outcomes. Finally, a certain state, s'_i obtains, and the decision maker receives value $u(s'_i, a'_j)$.

The valuation of the information source occurs *ex ante*, before any signals are received, actions are chosen, or states obtain. Thus, it must deal in expected quantities. The value of an information source is defined as the difference between the expected value with the information source and the expected value without.

$$V = EV(N) - EV(\emptyset)$$

If no source of information is used, the decision maker will choose an action based upon prior probabilitites of states of nature occuring. Specifically, he will choose a_j' which maximizes the expected value of the outcome.

$$EV(a_j) = \underset{s_i}{SUM} \{p(s_i)u(s_i,a_j)\}$$

$$EV(\emptyset) = EV(a_j') = \underset{a_j}{MAX} \{EV(a_j)\}$$

$$= \underset{a_j}{MAX} \underset{s_i}{SUM} \{p(s_i)u(s_i,a_j)\}$$

If a source of information is used, the decision maker will choose an action based upon his revised probabilities of states occuring. Assume for a moment that signal y_k' is produced. Then the decision maker computes $p(s_i|y_k')$ for all s_i using the Bayesian revision formula:

$$p(s_i|y_k') = \frac{p(y_k'|s_i)p(s_i)}{\underset{s_i}{SUM} \{p(y_k'|s_i)p(s_i)\}}$$

Each quantity on the right hand side is a known primitive. The problem is again the choice of an action a_j' to maximize the expected value of the outcome.

$$EV(a_j|y_k') = \underset{s_i}{SUM} \{p(s_i|y_k')u(s_i,a_j)\}$$

Thus, after the signal y'_k obtains, the problem is to choose a'_j, where:

$$EV(a'_j | y'_k) = \underset{a_j}{MAX} \{EV(a_j | y'_k)\}$$
$$= \underset{a_j}{MAX} \underset{s_i}{SUM} \{p(s_i | y'_k) u(s_i, a_j)\}$$

Signal y'_k will occur with probability $p(y'_k)$. The information source evaluator can calculate $p(y'_k)$ using the formula:

$$p(y'_k) = \underset{s_i}{SUM} \{p(y'_k | s_i) p(s_i)\}$$

Again, each quantity on the right hand side is a known primitive. Thus, before any signal is received, the probability of receiving each signal and the expected value of the outcomes for each signal can be computed. Then, the expected value of outcomes for using the information source, N, is:

$$EV(N) = \underset{y_k}{SUM} \{p(y_k)[\underset{a_j}{MAX} EV(a_j | y_k)]\}$$
$$= \underset{y_k}{SUM} \{p(y_k)[\underset{a_j}{MAX} \underset{s_i}{SUM} \{p(s_i | y_k) u(s_i, a_j)\}]\}$$

The value of the information source is now readily deducible as the difference of two computed quantities.

$$V = EV(N) - EV(\emptyset)$$

Notice that this model concerns a problem within a problem. There is the problem of choosing an action and there is the problem of valuing the information system. We can call these the decision maker's problem and the information system evaluator's problem, respectively. The evaluator is assuming that the decision maker is acting perfectly rationally. Under this assumption this is a valid model of the value obtainable by the decision maker from the information source.

For an economically irrational decision maker, the obtainable value of the information source may be more or less than predicted by this model. This is because the value of the information source is a difference between two expected quantities. To demonstrate this, let us represent the expected value of the outcomes of the economically rational decision maker by EV and of the economically irrational decision maker by EV'. Then we have:

$$EV(N) \geq EV'(N)$$

$$EV(\emptyset) \geq EV'(\emptyset)$$

This is true because the economically rational decision maker always has the option of behaving exactly like the irrational decision maker. But note, we can say nothing about the relative magnitude of $EV(N) - EV(\emptyset)$ and $EV'(N) - EV'(\emptyset)$. Thus, it is interesting to note, an information source may have more value to an economically irrational decision maker than to a rational decision maker.

To move to the multiple source model, only the revision of probabilities of states of nature must be changed. The decision maker needs the matrix of probabilities $\{p(y_k | s_i)\}$ for each source, so that the probability of each state obtaining can be revised for every possible combination of signals. The Bayesian revision formula to accomplish this is significantly more complicated than for the single source model, but conceptually the same.

The multiple decision problem further complicates the model, because a signal at any point in time can potentially impact every future decision. The formulation of this model over a fixed time horizon, where every decision problem is known in advance, becomes a rather messy dynamic programming problem.

AREAS OF MODIFICATION

These economics models of information value poorly describe the roles of information in managerial decision making and hence poorly reflect the obtainable value of information in realistic managerial settings. The descriptive inadequacies of these models have been organized for discussion into five sections. In each, possible modifications of the models, as suggested by a reading of other related fields of study, are indicated. We conclude with some remarks on the difficulty of implementing such modifications and the efficacy of this approach.

1. The Decision Process

According to economics models, information derives value from its effect upon the decision process. This orientation is difficult to fault if decision making is interpreted broadly, for almost all managerial activities which use information can be classified as some phase of the intelligence-design-choice-review decision process.[Simon 1965, p. 54] Simon writes:

> Decision making comprises four principle phases: finding occasions for making a decision, finding possible courses of action, choosing among courses of action, and evaluating past choices. These four activities . . . . account for most of what executives do.[Simon 1977, p. 40]

Mintzberg's study of the work of five chief executives reinforces this finding.[Mintzberg 1973, p. 250] All but time spent in ceremonial activities (12 percent) and in giving information (8 percent) is attributable to one or more phases of decision making.

Witte[1972] formally tested for the existence of different phases in the decision process using a sample of 233 decisions to aquire computer equipment. He divided each decision process into ten equal time periods and characterized each activity in each period as information gathering, alternatives development, alternatives evaluation, or choice. The evidence supported the hypothesis that multiple phases exist within the decision process.

The difficulty with the economics models is that they concentrate upon only one phase of decision making, the choice among alternative courses of action. They assume that an occasion for decision making has been found and that all possible courses of action and consequences for every conceivable course of events have been determined. But, by the time these assumptions are satisfied, managers have already used a great deal of information and expended the majority of their effort on the problem.[Simon 1977, p. 40] Decisions are profoundly affected by information at the intelligence and design phases of the decision making process, because without information to identify problems, structure alternatives, and estimate consequences, no choice is ever made.

It is evidently necessary that the economics models of information value be expanded to include consideration of these earlier phases, intelligence and design, if they are to accurately reflect the benefits of information. The final phase, review, need not be explicitly modelled since it is usually part of the intelligence phase of other decisions, and could be captured as such in a multiple decision model.

The phase theory of decision making implies not only that decisions are comprised of different activities, but also that these activities follow a set pattern, a progression from initial recognition to implementation of the chosen actions. Witte's evidence does not support the hypothesis that the phases followed a clear progression. Even when each decision was divided into subdecisions, no support for the hypothesis was found.

Mintzberg, Raisinghani, and Theoret[1976] also found evidence of cycling through phases during the decision process, in their study of twenty-five strategic decision processes in different organizations. They suggest that cycling is used as a means of comprehending and clarifying complex decision processes and that "the most complex and novel strategic decisions seem to involve the greatest incidence of comprehension cycles".[p. 265] Evidence was also found that interrupts, created by internal and external pressures and by the appearance of new options, caused cycling.

The authors build their findings into an elaboration of the simple intelligence-design-choice model and posit that intelligence is comprised of two routines: decision recognition and diagnosis. Diagnosis is an optional routine used to clarify and define the issues. Decision recognition occurs when there are sufficient signals about either a crisis, a problem, or an opportunity. This catagorization of problems by stimulus was first suggested by Carter[1971] in his study of six strategic decisions within one company. The earlier theory of Cyert and March suggested that decision recognition was always a response to problems rather than to perceived opportunities.[1963, p. 116]

Pounds[1969] has presented a theoretical structure for analysing problem identification, one type of decision recognition, as a process of comparing information about real events against the predictions of a chosen 'model' of normality. The models managers use are implicit or explicit derivations from historical and planning data or models imposed by others or derived from outside the organization.

There exists no design for design; this phase of decision making is not well understood. Cyert and March[1963] posit that design is largely a matter of problem-directed search for acceptable alternative actions. How this search is accomplished, though, is somewhat less than clear.

Mintzberg, Raisinghani, and Theoret suggest that design activity is very different depending upon whether the decision maker sought a ready-made or a custom-made solution. They note that search is appropriate for ready-made solutions, but that more elaborate models are necessary for the description of the design of custom-made solutions. Reitman[1964] has further detail on the various forms of design activity.

In summary, there is general agreement in the literature that intelligence and design activities exist as important phases of the decision process. The exact nature of each phase and their order from decision recognition to decision implementation is somewhat less than clear. All of the work implicitly suggests several roles for information. This information has value equivalent to the expected improvement (which may be zero) from knowledge of the information. The addition of some consideration of the intelligence and design processes to the model should provide a more accurate evaluation of the managerial uses of information.

2. Human Judgement Under Uncertainty

There are two competing paradigms of the utilization of information in judgement and choice, the Bayesian and the regression schools of thought. The essential difference between the two is in the manner of assessment of the relationship between information and the states about which one is drawing inference. The Bayesians propose the use of conditional probabilities and Bayes' theorem to assess the impact of information upon prior judgements of the states' probability of obtaining. The regression school, formalized in the lens model proposed by Brunswik [Brunswik 1952, 1956], uses correlations of states with information cues to weight the importance of each cue in the final judgement. After several hundred psychology studies of human judgement, the rivalry between the two schools remains intense. Despite obvious conceptual overlap, attempts at unifying the two views have met with limited success.[Slovic and Lichtenstein 1971, van Breda 1973]

Economics has adhered to the Bayesian view of information utilization ever since Savage first joined the concepts of utility and subjective probability into a formal, axiomatic theory of decision making.[Savage 1954] This is why the economics information value models require that the decision maker have knowledge of the probability functions $p(s_i)$ and $p(y'_k|s_i)$, for the derivation of $p(s_i|y'_k)$, the probabilities of each state obtaining revised upon receipt of signal y'_k. It is a curious formulation of the decision maker's problem (as apart from the information source evaluator's problem), for it is a simpler matter to produce directly subjective estimates of $p(s_i|y'_k)$ in the presence of y'_k, than to estimate both $p(s_i)$ and $p(y'_k|s_i)$ and apply the Bayesian revision formula. The economics model of how we arrive at the function $p(s_i|y'_k)$ appears to be a valid description of human behavior only under the assumptions that the intelligence and design phases are complete, that $p(s_i)$ and $p(y'_k|s_i)$ are already given. As discussed in the previous section, we must remove such assumptions from the model.

Reformulation of the model to indicate direct estimation of $p(s_i|y_k)$ by the decision maker simplifies the decision maker's problem, but leaves the information valuation problem almost unchanged. The calculation of information source value still requires knowledge of $p(y_k)$, which is not directly estimatable, but can be most easily derived from $p(s_i)$ and $p(y_k|s_i)$. Notice that the economics model of information value had the decision maker's and the information source evaluator's primitive data type requirements coincide. When the model is descriptively enhanced, the data required by the decision maker and the data required for evaluation of an information source become disconnected. This has interesting implications for the ability of decision makers to evaluate their own sources of information. We shall not pursue them here.

Further complications must be considered in modelling the decison maker's direct estimation of $p(s_i|y'_k)$. There is a large and growing body of psychology literature that documents and theorizes on evidence of systematic bias in the estimation of probabilities. Tversky and Kahneman have identified three important heuristics by which people estimate probabilities and have demonstrated how these lead to systematic biasing of estimates.[Kahneman and Tversky 1973; Tversky and Kahneman 1971, 1974] The 'prospect theory' they have developed sheds considerable light on how outcomes are framed as gains and losses in evaluating utilities and on the transient nature of these values. [Kahneman and Tversky 1979; Tversky and Kahneman 1981] A model of information value needs to include consideration of these systematic biases, for they induce a systematic subutilization of information, and decrease the obtainable value of information.

3. The Choice of Actions

Economics information value models require that the decision maker explore the consequences of every action, from their potential action set A, in every state of nature in S. He chooses the action which maximizes the expected value of outcomes. This is apparent from the formula for EV(N) in the information economics model we reviewed. There is considerable evidence that actions are chosen on a much simpler basis.

Simon was one of the first to question the maximum expected value model of choice. He developed the well known idea of satisficing, and submitted it as a better description of individual behavior and as a normative model of rational behavior under conditions of costly information gathering and processing.[Simon 1955, 1956, 1957, 1959] He suggested that an action choice rule more descriptive of human behavior would be to determine a minimum aspiration level, L, for a decision outcome and sequentially search and test potential actions, a , until an action a' is found such that:

$$\underset{s_i}{\text{MIN}}\ u(s_i, a'_j) \geq L$$

In this formulation, $u(s_i, a'_j)$ need not be accurately determined; one only needs to know whether $u(s_i, a'_j)$ is greater than L, the level of aspiration. L and $u(s_i, a'_j)$ could be multidimensional. Then, the action choice rule need not be modified, but the chosen action a'_j must satisfy the rule along every dimension. This obviates the need for a tradeoff among dimensions of the objective.

Cyert and March extended this idea to the theory of the firm [Cyert and March 1962] and considerable work has continued in this area, bounded rational theory.[March 1978] Stigler has explored the economics of the search activity.[Stigler 1961] Many of these ideas could simplify a model of information value and serve as a better description of decision making behavior.

Soelberg[1966, 1967] studied the behavior of fifty-two graduate students making job decisions. He found evidence that individuals had more than one acceptable choice alternative before ending their search, in contradiction to strict satisficing behavior. Soelberg developed a theory of decision making that combines the notions of maximizing along the most important one or two dimensions of outcome and satisficing along all others, to explain his findings.

The conflict between Simon's and Soelberg's theories of choice behavior can be resolved using Mintzberg, Raisinghani, and Theoret's differentiation between ready-made and custom-made solutions. They write, "The hypothesis with the strongest support in our study is that the organization designs only one fully-developed custom-made solution. . . In contrast, organizations that chose ready-made solutions typically selected them from among a number of alternatives".[1976, p. 256] Soelberg's sample was of decision makers seeking and choosing from among ready-made solutions (job offers), whereas many of Simon's conclusions appear to have germinated from his observations of problems involving custom-made solutions, such as the widely referenced description of a computer aquisition decision made in the early 1950's.[Cyert, Simon, and Trow, 1956]

Different simplified choice rules could also be modelled. For example, one could model the practice of developing plans based upon assumptions about most likely future scenarios. This is equivalent to identifying the most likely state of nature and choosing an action to maximize the value of the outcome if that state obtains. The decision rule would be, choose a'_j, such that:

$$u(s'_i, a'_j) = \underset{a_j}{\mathrm{MAX}}\, u(s'_i, a_j)$$

$$\text{where} \quad p(s'_i | y'_k) = \underset{s_i}{\mathrm{MAX}}\, p(s_i | y'_k)$$

Several variations of this simplification are possible.

4. Multiple Signal Resolution

There is little evidence that individuals resolve multiple and possibly conflicting signals through a complex Bayesian revision process. Even 'Bayesian' psychologists have developed theories about individuals' misaggregation of multiple signals to explain the apparent conservative revision of prior probability estimates.[Beach 1968; Edwards 1968; Gettys and Manley 1968; Wheeler and Beach 1968; Tversky and Kahneman 1974] The regression paradigm offers no better description of multiple signal resolution. Contrary to its predictions, experiments have indicated that increased numbers of signals lead to decreased accuracy and lower test-retest reliability of judgements of probabilities.[Hoffman and Blanchard 1961; Hayes 1964; Einhorn 1971]

Possibly, the heuristic used to resolve multiple signals may be modelled more closely as a voting process, with each signal weighted by the reliability of its source. Sufficient conflict among signals could lead to decreased confidence and an increased propensity to collect more information.

As with modelling the design phase of the decision process, the direction to take in modelling multiple signal resolution is not clear. Nevertheless, it should be possible to improve upon the descriptive ability of the complex Bayesian revision process adopted by information economics.

5. Multiple Decisions Over Time

How do managers deal with information over time? The economics models assume that they design all future decision problems at the beginning of a finite time horizon.[Feltham 1968, 1972] In this context, an information source is valued as the present value of the expected stream of outcome improvements gained by a decision maker using information signals optimally. The solution to this problem can only be derived using dynamic programming, for one considers the impact of each signal in the present decision as well as in all future decisions. It is not the reuse of the information source, but of the particular information signals that makes the decision maker's problem so absurdly counter to intuitive notions of managerial behavior.

The economists appear to have been trying to model the use of historical information in decision making. This might be accomplished much more simply if we do not separate the information source from historical information. In this way, the new information signals may embody historical information and the overwrought complexity of the problem disappears.

The other major modification of the multiple decision problem has already been suggested in an earlier section. Decision problems cannot be defined and enumerated at the beginning of any period of time. They must be discovered, selected, or assigned with little forewarning. We have suggested that this problem identification issue can best be described by adding an intelligence phase to the model.

CONCLUSIONS

We have reviewed a standard model of the value of information from economics theory and criticized it from the perspective of descriptive validity. Five major areas of revision have been discussed. Revisions in these areas would bring the model into closer alignment with our knowledge of the behavior of managerial decision making.

This paper has set a direction, but made little movement in the chosen direction. To guide our future path we need a goal as well as a direction; we need a conception of the final product, qualitative requirements for the final model that we wish to create.

Our requirements are two. The model should be simple and complete. By simple, we mean that it should be free from unnecessarily detailed considerations. Individual decisions may have to be aggregated into 'decision areas' in the final model. Preference functions may have to be simplified. By complete, we mean that the model should capture the major uses of information which derive benefit for the firm. Our suggestions for expanding the decision process should help us greatly in this regard.

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FEB 2 '84	MAY 07 1989
JAN 13 '85	OC 16 '89
SEP 4 1985	JAN
JUL 20 1986	MAY 16 1990
DEC 19 1986	JUN 30 1990
FEB 17 1987	JUN 18 1992
MAY 15 '87	MAR 3 1996
OC 14 '87	JUN 02 1999
AP 07 '88	

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BOOKBINDING CO., INC.
NOV 10 1983
100 CAMBRIDGE STREET
CHARLESTOWN, MASS.

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Van Breda, Mic/Interpreting inflation
742013 D*BKS 00132633
3 9080 001 995 882

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742002 D*BKS 00133056
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742616 D*BKS 00133580
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Rotemberg, Jul/Sticky prices in the Un
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