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A MEASURE OF INFORMATION SYSTEM EFFICIENCY*

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Introduction

The information system of the firm can be considered a network. Each line of this network represents a channel of communication, and each node a decision center, an information center, or both. As a decision center, a node can be viewed as receiving information and issuing decisions (information). In the past, interest in nodes has been confined to decision making. Another important aspect of these nodes is the effectiveness of the information system serving them. How effectively are the information inputs serving the decision maker at each node?

A solution to this problem, measurement of the effectiveness of the information system for a specific decision maker, is proposed in this paper. It is an ex post measure, based upon the Simon satisficing model of the decision making process.

The necessary informational requirements of the decision maker are derived from the Simon model. These necessary informational requirements are incorporated into an efficiency vector of the information system. For any decision such a vector can be generated. This efficiency vector is an ex post measure of the efficiency of the information system, at a node, in serving the decision maker with a specific problem, at that node.

This measure is to be applied after a decision is made. The characteristics which are incorporated into the measure are:

$e_4 = 1/2 \left[(n_4 - n_5)/(n_4 + n_5) + 1\right]$; refinement of information

$e_5 = 1/h$; favorable display bias.

For these the following relationships exist:

$1 \geq e_1, e_2, e_3, e_4, e_5 \geq 0$

The elements e_1, e_2, and e_3 are relative measures of the successive degrees of completeness of the information. The least complete information is a listing of alternatives and the most complete is the same listing with these added characteristics: outcomes known or unknown, outcomes acceptable or unacceptable, and extreme or moderate probability values. Successive degrees of completeness are measured to indicate information system performance in furnishing these various types of information. The element e_4 is a relative measure of the processing and search of the information system beyond that initially performed. The element e_5 is a relative measure of how readily the alternative finally chosen was found by the decision maker.

The Satisficing Model

The elements of the decision making process in the satisficing model, called the primitive terms and definitions by Simon, are the following:[2]

1) A set of behavior alternatives, represented by a point set A.

2) The subset, $A_o \subset A$ which is perceived by the decision maker.

3) The perceived future state of affairs or outcomes of choices, represented by a set of sets S.

4) A payoff function representing the value placed by the organism upon each of the perceived outcomes of the alternative chosen.

5) A list of the perceived set of outcomes (s_i) in S for each alternative a_i. This is the mapping of the elements of A_o to S_o.

6) The probability that outcome s_{ij} will occur if alternative a_i is chosen. This can be represented as the conditional probability $P(s_{ij}/a_i)$.

7) A criterion to be satisfied, namely a certain value (*) of the payoff function (V). We shall define this as the aspiration level V(*).

These quantities, their definitions, and relations are listed below:

$A_o \equiv$ the set of perceived alternatives.

$A_o \equiv (a_1, a_2, \ldots, a_i, \ldots, a_n), \quad 0 < n < \infty$

$a_i \equiv$ alternative i.

$S_o \equiv$ the set of sets of known outcomes to the perceived alternatives.

$S_o \equiv (s_1, s_2, \ldots, s_i, \ldots, s_n), \quad 0 < n < \infty$

$s_i \equiv$ the set of perceived outcomes of alternative i.

$s_i \equiv (s_{i1}, s_{i2}, \ldots, s_{ij}, \ldots, s_{im}), \quad 0 < m < \infty$

$s_{ij} \equiv$ a perceived outcome if alternative i is chosen.

$P(s_{ij}/a_i) \equiv$ the conditional probability that outcome s_{ij} will occur if alternative i is selected.

$V(\ ) \equiv$ the payoff function

$V(s_{ij}) \equiv$ the payoff if outcome s_{ij} occurs.

$V(*) \equiv$ the decision maker's aspiration level in terms of a payoff.

The information system plays a role in the decision process by supplying information about: (1) available alternatives, (2) the possible outcomes of

some of the available alternatives, (3) the mapping of elements of A_o to S_o, and (4) the probability, $P(s_{ij}/a_i)$.

From the information provided about these, the decision maker considers the payoff $V(s_{ij})$ of each possible outcome of alternative a_i. After comparing $V(s_{ij})$ with his aspiration level $V(*)$ the decision maker then determines, for those outcomes which are acceptable, (i.e., $V(s_{ij}) \geq V(*)$), the probability of their occurrence, $P(s_{ij}/a_i)$. All a_i's that have an s_{ij} such that $V(s_{ij}) \geq V(*)$ and $P(s_{ij}/a_i) \approx 1$ (i.e., close to one) will satisfy him.

The Measure in General

The measure has distinct characteristics derived from the phenomenon measured and the need for the measurement. There are four of these: the form of expression; the measure type; the criterion of necessity of informational requirements; and the unit of analysis.

The Form of Expression

Several properties of the unit of analysis are expressed in the measure. These properties are distinct and must be considered separately. They have no common denominator. Consequently the best form of expression is the familiar vector notation.

The Measure Type

A common measure of efficiency is the ratio of actual and potential performance. For example, in Thermodynamics, we say that a heat engine is 50% efficient if the ratio $(\text{Work})_{out}/(\text{Heat})_{in} = 1/2$. The features of such

a dimensionless measure are: (1) maximum efficiency is equal to one, (2) minimum efficiency is equal to zero and (3) any other performance will have an efficiency between zero and one. If we use a similar measure for each of the elements of an efficiency vector (E), the point represented by the vector must be included within the unit n-dimensional sub-space or at most be on its surface; and the maximum point would be the vertex, E = (1, 1,...., 1).

A relative rather than an absolute measure is being used because of the need for a clearly defined maximum as a standard, and because comparisons between nodes, of system efficiency, are best made by the use of such a measure. Thus, for the particular viewpoint we are assuming, (i.e., evaluating the information system from the decision maker's viewpoint), a relative measure seems to be the appropriate one.

Because of the subjective nature of the viewpoint from which the information system is to be evaluated, a relative measure is perhaps more meaningful than an absolute one. The valuation of information is to be based on the decision making process of the decision maker and subjective elements such as his experience, previous knowledge, etc., must somehow come into play. These are incorporated into a ratio measure.

<u>The Criterion of Necessity of Informational Requirements</u>

Each element of the efficiency vector represents a necessary aspect of information, (i.e., an information requirement is an element

only if it is necessary). The necessity of an information requirement is defined as follows: An information requirement x is said to be necessary if within the context of the decision making model assumed, arriving at a decision is rendered impossible without x. For example, with the satisficing model, satisfactory alternative content of information is a necessary requirement.

The Unit of Analysis

We shall use as the unit to be evaluated the decisional unit of information. A decisional unit of information consists of all the information that the information system provides at a node for a specific decision. There is no requirement of exclusiveness of information; the same set of information may be used for several decisions. The determining factor of the unit is the decision for which the information is generated.

This decisional unit of information is consistent with an implicit assumption about the information system. In the absence of any decision making in the firm, there seems to be no need for information. The decisional unit thus definitely incorporates this assumption by assuming that for the most part, information is geared to some decision.

Since it is possible for decisions to be subdivided further into subdecisions, a decisional unit can also be subdivided into finer units--subunits. This gives our evaluation model a certain degree of flexibility since the efficiency vector should be applicable to both the complex decision as well as its subdecisions.

The Dimensions of the Measure

Earlier,[3] we stated that within the context of the satisficing model the information system plays a prominent role by supplying the following types of information: (1) the perceived alternatives; (2) the perceived outcomes; (3) the correspondence between alternatives and outcomes; and (4) the probability of an outcome, given an alternative. From these, we wish to derive some of the elements of the efficiency vector.

Since these dimensions are really informational requirements which are necessary for decision making, three are immediately apparent. First, the information has to contain useful alternatives for the decision maker, thus the "outcome content" of information is one dimension. Similarly, the "alternative content" and the "probability content" of information comprise two additional dimensions. Information presentation is the source of two other dimensions, refinement of information and display bias.

Thus the proposed efficiency vector of the information system has five elements. The necessity of each element and the measurement of efficiency along each dimension will be the subjects of the following sections. In general, the evaluation will be made after a decision has been made, not before. What we wish to measure is the efficiency with which the system has served the decision maker in reaching a decision.

Outcome Content of Information

The decision maker must determine if for every a_i in A_o, there is a corresponding s_i (the set of all perceived outcomes of a_i) in S_o, the set of sets of outcomes. Thus $s_i \equiv (s_{i1}, s_{i2}, \ldots, s_{ij}, \ldots, s_{im})$ where each s_{ij} is one of the perceived outcomes of a_i.

Let

$n \equiv$ the number of perceived alternatives; the elements of A_o,

$n_1 \equiv$ the number of alternatives with sets of known outcomes; the elements of S_o,

$e_1 \equiv$ the measure of the outcome content of information, then,

$e_1 \equiv n_1/n.$

Hence, MAX $e_1 = 1$ when $n_1 = n$ and MIN $e_1 = 0$ when $n_1 = 0$.

For example, if $e_1 = 0.50$, only half the perceived alternatives have known outcomes.

Satisfactory Alternative Content

The decision maker is interested primarily in those alternatives which have known outcomes that are acceptable. Acceptable outcomes are the set of outcomes S_1 defined as follows:

$S_1 \equiv \{$set of all s_i in S_o such that there exists at least one s_{ij} in each s_i for which $V(s_{ij}) \geq V(*)\}$; $\{s_i \mid s_i \in S_o, \forall\, s_i \in S_o \,\exists\, s_{ij} \in s_i \ni V(s_{ij}) \geq V(*)\}$

Let $e_2 \equiv$ satisfactory alternative content,

$n_1 \equiv$ the number of perceived alternatives which have outcomes,

$n_2 \equiv$ the number of perceived alternatives which have acceptable outcomes; the count of the elements of S_1, Outcome Content of Information

The decision maker must determine if for every a_i in A_o, there is a corresponding s_i (the set of all perceived outcomes of a_i) in S_o, the set of sets of outcomes. Then $s_i = (s_{i1}, s_{i2}, \ldots, s_{ij}, \ldots, s_{in})$ where each s_{ij} is one of the perceived outcomes of a_i.

Let

m = the number of perceived alternatives, the elements of A_o.

n_i = the number of alternatives with sets of known outcomes, the elements of [illegible].

v_i = the measure of the outcome content of information.

$v_i = n_i/m$

Hence, [illegible] v_i [illegible] and [illegible] v_i [illegible]

For example, [illegible] the perceived alternatives [illegible]

[illegible]

[illegible]

[illegible]

then $e_2 = \frac{n_2}{n_1}$ and

MAX $e_2 = 1$ when $n_2 = n_1$, and MIN $e_2 = 0$ when $n_2 = 0$, (i.e., $S_1 = \emptyset$).

Probability Values

Given our decision making model, the probability values, $P(s_{ij}/a_i)$, are necessary data for the decision maker. But the decision maker does not like uncertainty and wishes to avoid it.[4] He does this by choosing highly predictable alternatives. Hence, one requirement within the decision making model is that the probability of a satisfactory alternative must be high before the decision maker can choose that alternative. Cyert and March indicate that this is common decision behavior within the firm.[5]

Since the decision maker prefers highly predictable alternatives, $P(s_{ij}/a_i)$ should be near zero or one, (i.e., the probability value should be extreme). The main variable of this element of the measure is the existence of information for the decision maker to gauge whether or not the conditional probability $P(s_{ij}/a_i)$ is near zero or one. The probability $P(s_{ij}/a_i)$ does not have to be defined for all $s_{ij} \in S_o$. The decision maker needs to know the probabilities of only those alternatives whose payoffs satisfy his aspiration levels. Specifically, $P(s_{ij}/a_i)$ should be known for all $s_{ij} \in S_1$ for which $V(s_{ij}) \geq V(*)$. Thus, if

$S_2 \equiv$ {the set of all s_i in S_1 such that for each s_{ij} for which $V(s_{ij}) \geq V(*)$, $P(s_{ij}/a_i) \approx 1,0$} ; $\{ s_i \mid s_i \in S_o, \forall s_i \in S_o \ \exists \ s_{ij} \in s_i \ni V(s_{ij}) \geq V(*), P(s_{ij} \mid a_i) \approx 1,0 \}$

then membership in S_2 is determined by the predictability of the outcomes. Furthermore, since the measure is calculated after a decision is made, there is always one s_i for which $V(s_{ij}) \geq V(*)$ and $P(s_{ij} \mid a_i) \approx 1$.

Let

$n_2 \equiv$ the number of perceived alternatives which have outcomes; the number of elements in the set S_1,

$n_3 \equiv$ the number of perceived alternatives with acceptable outcomes which have extreme probability values; the number of elements in the set S_2,

$S_o \subseteq S_1 \subseteq S_2$

$e_3 \equiv$ the measure of the number of extreme probability values,

then $e_3 \equiv n_3/n_2$,

and MAX $e_3 = 1$ when $n_3 = n_2$ and MIN $e_3 = 0$ when $n_3 = 0$. As in the other dimensions, e_3 is to be measured after the decision has been made. This precludes e_3 being undefined when $n_2 = 0$.

The Refinement of Data

Data is processed to produce information such as the alternatives available. For a given set of data which contains a fixed number of alternatives, the alternatives perceived by the decision maker are, relative to him, a function of the processing. We assume that the number of perceived alternatives is a monotonic increasing function of processing. Additional processing of data may increase the number of alternatives contained in a set of information, it may increase the obviousness of those alternatives which were present but

relatively less obvious, and it may initiate search for additional alternatives not in the original data; this requires supplementary data. The fewer alternatives the decision maker requires in addition to those initially perceived, the more efficient the information system.

Let

e_4 ≡ the measure of refinement of the information,

n_4 ≡ the number of alternatives perceived initially,

n_5 ≡ the total number of alternatives perceived,

then $n = n_4 + n_5$,

and $e_4 = k_1 \ [(n_4 - n_5)/(n_4 + n_5) + k_2]$

where k_1 and k_2 are normalizing factors which would make $e_4 = 0$ at the minimum and equal to one at the maximum. Clearly, $k_1 = 1/2$ and $k_2 = 1$, which makes

$$\text{MIN } e_4 = 0 \quad \text{when} \quad n_4 = 0 \quad \text{and}$$

$$\text{MAX } e_4 = 1 \quad \text{when} \quad n_5 = 0 \ .$$

Thus,

$$e_4 = 1/2 \ [(n_4 - n_5)/(n_4 + n_5) + 1]$$

When the initial set of information offers no alternatives but a subsequent set does, then $e_4 = 0$. Thus, the minimum of e_4 merely implies a deficiency of the initial set and not necessarily the total set of information provided. This element of the measure is a comparison between an initial and the terminal state of the decisional unit. All the other elements deal only with the terminal state.

The Display Bias

Another aspect of the presentation of information relates to its display characteristics. Display characteristics include the media of communication (e.g., whether oral or written), the particular format being used, etc., and affect the amount of search the decision maker must perform. Search and perception are independent although both may be part of the same process or system. Perception is the act of recognition; the realization that a predetermined pattern or set of characteristics have been fulfilled. Search is the process of selecting the elements of a set of information for determination of pattern or characteristics fulfillment.

Since it has been found that the search for alternatives is sequential,[6] how the information is presented will produce a bias in the search. For example, the underlined portions of a report will almost always attract attention. Similarly, relaying the information personally or by telephone would tend to give it more importance than if it were included in a routine report.

The problem of search bias is compounded by the fact that to a large extent the order of the search is also a function of the decision maker's knowledge, experience and, in general, his abilities and characteristics. Thus, besides the cues which are supplied by the format of the report, the individual characteristics of the decision maker determine where he starts his search for alternatives.

There are n elements in the set of perceived alternatives A_o. These can be ordered according to their appearance in the sequential search: $A_o = [a_1, a_2, \ldots, a_h, \ldots, a_n]$ where a_h is the h^{th} alternative perceived in the search and $1 \leq h \leq n$.

In general the decision is to select the h^{th} alternative, a_h. Thus if we define

$n \equiv$ the number of alternatives of A_o,

$e_5 \equiv$ the measure of favorable display bias,

then

$e_5 = 1/h$, where a_h is the alternative chosen.

Hence, MAX $e_5 = 1$ when $h = 1$ and MIN $e_5 = 1/n$.

Low values of e_5 mean that the display characteristics of the information are poor.

Among the first three elements (e_1, e_2 and e_3) of the measure the following relation and conditions exist.

$e_1 e_2 = \frac{n_1}{n} \frac{n_2}{n_1} = \frac{n_2}{n} \equiv$ percent of perceived alternatives that have acceptable outcomes

$e_2 e_3 = \frac{n_2}{n_1} \cdot \frac{n_3}{n_2} = \frac{n_3}{n_2} \equiv$ percent of perceived alternatives with outcomes that have extreme probability values

$e_1 e_2 e_3 = \frac{n_1}{n} \frac{n_2}{n_1} \frac{n_3}{n_2} = \frac{n_3}{n} \equiv$ percent of perceived alternatives with acceptable outcomes that have extreme probability values

$e_1 = 1$ iff $n = n_1$

$e_2 = 1$ iff $n_1 = n_2$

$e_3 = 1$ iff $n_2 = n_3$

$e_1 e_2 = 1$ iff $n = n_2$

$e_2 e_3 = 1$ iff $n_1 = n_3$

$e_1 e_2 e_3 = 1$ iff $n = n_3$

$n = n_2$ iff $n = n_1 = n_2$ since,

by definition, $n \geq n_1 \geq n_2$

$n_1 = n_3$ iff $n_1 = n_2 = n_3$ since, by definition, $n_1 \geq n_2 \geq n_3$.

$n = n_3$ iff $n = n_1 = n_2 = n_3$ since

by definition $n \geq n_1 \geq n_2 \geq n_3$.

It is possible for e_1 , $e_3 = 1$ and $e_2 < 1$ this can occur iff

$n = n_1 > n_2 = n_3$. Also, in this case,

$e_1 \, e_2 < 1$

$e_2 \, e_3 < 1$

$e_1 \, e_2 \, e_3 < 1$

$e_1 \, e_2 = e_2 \, e_3 = e_1 \, e_2 \, e_3 = e_2$

since e_1 , $e_2 = 1$ by the conditions stated (i.e., $n = n_1 > n_2 = n_3$)

Summary

The measure proposed here is based upon the assumption that the information system satisfies the decision maker with respect to a specific decision by furnishing him sufficient information to make that decision. Thus the measure does not indicate whether or not the information system meets the basic demands of the decision maker; it is assumed that it does.

What is proposed here is a measure of how efficiently the information system satisfied the demands of the decision maker rather than whether or not it satisfied his demands. Consequently, the components of the measure are calculated after a decision has been made.

The measure is of system efficiency given a specific individual and a specific decision. If any one of these three change, the relative efficiency of the system will change and must be recalculated. The measure has been described already as subjective. It is also a partial measure since it does not indicate graduations and it does not measure other important characteristics such as the distribution of related information (i.e., bunched or scattered). In addition the measure does not indicate what might have been; it does not compare the information supplied to the decision maker with what could have been supplied.

The merit of this measure is that it indicates some of the aspects of the information system which can be improved in a specific decision-making situation. It does indicate to a degree how to make the improvement.

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Footnotes

1. The alternative content of information is defined as the number of alternatives to the decision or problem, supplied by the information system.

2. Items (1) to (6) are from Herbert A. Simon, Models of Man, (New York: John Wiley and Sons, 1957), p. 244. Item (7) is from James G. March and Herbert A. Simon, Organization (New York: John Wiley and Sons, 1958), p. 48.

3. Page 4 and 5.

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