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Information Quantity Assessment

Bases for Managing the Information Resource

by

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Abstract

This thesis proceeds from the assumption that information is a valuable asset in need of more direct management attention. Information's intangible nature creates difficulties in measuring it directly, however, which in turn makes it difficult to manage. By proposing a classification scheme called an Information Quantity Assessment (IQA), the thesis seeks to provide a basis for managing information.

Chapter 1 offers interpretations of the value of information and characterizations of the obstacles which have prevented the development of useful managerial tools. Overcoming these barriers is a primary concern of the IQA framework.

Chapter 2 examines existing theories of information value through a review of current literature. As certain of the existing theories are rather technical, interested readers are referred to Appendices where relevant mathematical equations are derived. The IQA framework builds upon existing concepts of value but introduces novel measurement concepts based on function. Chapters 3 and 4 define a system of information types and indicate practical applications.

Proposed applications of the IQA framework deal with specific uses of information to solve problems. In addition to problem solving, the proposed measures yield indices for efficient information management. The aim is that IQA will be both theoretically important and practically useful.

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CHAPTER 1

> Obviously, a man's judgement cannot be better than the information on which he has based it. Give him the truth and he may still go wrong when he has the chance to be right, but give him no news or present him only with distorted and incomplete data...and you destroy his whole reasoning process... -- *Arthur Hays Sulzberger*

> From Saudi Arabia and the Soviet Union to Western Europe and East Asia, the entire structure of power that held the world together is now disintegrating. A key, unnoticed reason for this global shake-up is the rise of a radically new system for wealth creation in which information ... plays a dominant role. -- *Alvin Toffler*

Introduction

The art of management involves the assignment of relative values which force tradeoffs among cost, quality, and schedule. Whether the yardstick is the economist's profit or the sociologist's quality of life, "managing" implies optimizing a series of choices to create the greatest value. Information constitutes the essential input to the management process. To describe an opportunity or to detail a problem, to manufacture a good or to service the result, to predict a likely outcome or to comprehend a mistake, the manager requires information. This obvious fact is frequently overlooked. Ironically, current management science manipulates information much less effectively than it manages property, cash, or personnel. Despite the importance of information, few tools exist to help manage it and fewer metrics exist to help disclose its value. This essay will address the critical issues in information management by establishing a theoretical foundation and then testing the hypotheses in a practical business environment.

The first section of this essay answers the question, "Why bother?" Industry has done well and could continue to survive without a theory of information management. What are the advantages of a successful theory and how do existing proposals address the pertinent issues? The second section presents a review of current literature in the field, and the third offers a formal proposal including a definition of terms and processes by which one might manage information. This section borrows from computer science and from artificial intelligence to offer a basis for manipulating categories of data. Information has long been a subject of study in these fields, and they contribute valuable theoretical foundations. The fourth section takes a pragmatic view. Can elements of the proposed theory be found in existing business? If not, where are the failings and where are the opportunities? Inconsistencies represent either a chance to improve the theory or a chance to improve business. For a testbed, this section examines information use in the air cargo industry, both because the industry is heavily information dependent and because a sufficient number of companies exist to help control for extraneous variables. The final section synthesizes the previous sections, contrasts theory with practice and compares the findings with the information goals set forth in the opening section.

The Need for a Theory of Information Management

Information unquestionably has value. At an abstract level, American society has implicitly placed a high value not only on information but on information transferral. The First Amendment to the Constitution, guaranteeing free speech, limits the power of government institutions by ensuring that all information and opinions pertaining to government activities can be freely discussed and published. This publicly available information, which guarantees social freedoms, is invaluable. Legal institutions seek to preserve not only the conduits of information, but also the integrity of its content. Those who deliberately disseminate untruths are subject to slander and libel laws, which judge their intent and the nature of injury caused

Another body of laws provides an inducement to generate and disseminate *new* information. Patent laws encourage citizens to develop new tools, processes and materials by providing an economic incentive in the form of monopoly rights.[1] The inventor receives legal protection provided that, in exchange, he discloses what he has learned. Patent laws assume that technological progress creates value. The existence of the U.S. Patent Office implies that collecting and publishing information is instrumental to this progress.

These social and legal institutions are dedicated to the production of information, the protection of its integrity, its collection and

[1]A design patent covering product appearance remains in effect for 14 years from the date of issuance by the U.S. Patent Office. Process patents covering functionality and physical properties remain in effect for 17 years. Neither patent is renewable except by act of Congress and both require the payment of fees at the time of filing, and in installments after 3.5, 7.5, and 11.5 years. *Guide to American Law: Everyone's Legal Encyclopedia*; Vol. 10.; St. Paul, MN: West Publishing Co © 1984. pp 104-5.

preservation, and its dissemination. Where, then, are the tools for managing the information created, collected, and distributed? Collective behavior has devised these information institutions as a means of achieving goals, such as scientific advancement. However, the institutions have emerged without an explicit attempt to manage data. A similar pattern emerges in business. Market research and simulation data serve the interests of the company in improving product design and profitability, and in capturing market share. Information management must be recognized as a subordinate yet proper subgoal to any strategic planning.

This thesis is intended to offer suggestions on information management in a business context. Information managers are not completely without tools. The spectrum of approaches ranges from the theoretical to the applied. Economists examine data from the perspective of utility curves.[2] Statisticians use decision theory and the Expected Value of Perfect Information (EVPI).[3] Computer scientists take a systems approach and consider it in terms of formal languages, relational database theory,[4] and decision support systems.[5] Accountants take the most applied view, measuring informativeness across corporate financial statements.[6] Touching on comparative ideas from various methodologies, the essay will address the following questions:

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[2]Hirschleifer, Feltham, Wilson

[3]Hamburg, Marschak, McGuire, Hilton.

[4]"A Relational Model of Data for Large Shared Data Banks;" E. F. Codd; in *Communications of the ACM*; Vol. 13, No. 6, June 1970; pp. 377-87.

[5]Adams, Zmud, Gorry & Scott Morton, Keen & Scott Morton.

[6]Lev.

(1) How does one measure information? Is there an information currency?
(2) How can information be classified and what are its relevant attributes?
(3) What information presents the most worthwhile investment opportunity and on what occasions should one buy, sell, or trade information?
(4) What frameworks will indicate the data that is captured or not captured by a corporation?
(5) Are there tools to measure information management efficiency?

Answers to these questions assume that information is essential to corporate health despite the fact that capital markets are comparatively unconcerned with assessing its value. Expressed by well-published economists and financial experts, the common view holds that "Assets fall into two broad categories, financial assets and tangible assets."[7] Corporate financial documents convey only the values of property, plant, equipment, and cash. They occasionally reflect the purchase price of intangibles through the financing of "goodwill." Capital markets advance corporate valuation methodology by considering a discounted series of future cash flows, revising their estimates depending on growth opportunities and the track records of key executives. Information in the form of databases, trade secrets, and process technology remains within an organization more surely than do its chief executive officers.

In general, however, information is not quantified. It is either not mentioned -- and therefore implicitly assigned zero value -- or it is grouped with goodwill intangibles including brand name value, research and development spending, access to distribution channels,

[7]*Macroeconomics* Fifth Edition; Rudiger Dornbusch and Stanley Fischer; New-York: McGraw-Hill © 1990; p. 122.

monopoly power, product and service quality, and other economic advantages. This aggregation makes it impossible to distinguish one intangible asset from another. The inevitable consequence is underinvestment in a factor which is not measured.

The Difficulty of Developing a Coherent Theory

Proposing a successful theory hinges in part on explaining the absence of metrics. Anecdotal support drawn from the legal system and from the professional literature arguing the need for information value assessment may seem obvious. However, if information carries great importance, why do so few systematic management tools exist for the purpose of managing business information? Existing information technology and conceptual tools almost universally manage information about tangible resources. They do not manage information. Instead, they manage inventory, cash flow or personnel. Almost no system now in use treats information *per se* as a separate commodity. Even among those few companies which profess to sell information, the customers are charged for access time and various forms of display regardless of whether any actual information is obtained.[8] For a system to qualify as an information manager, it must fundamentally address the question, In which *information* should one invest? Answering this question poses several additional problems concerning the quantification of value.

The first of these problems is the absence of an information currency. Information is conceptually vague, much more so than cash,

[8]See the DIALOG *Service Price List*, for example. This list charges for types of databases, connect time, and downloading. Whether a search reveals any data at all, the user is charged the same. There is an implied charge for the *amount* of data downloaded due to the increased transmission time. If an entire string of 0s were downloaded, however, the charge would again be the same.

for which numerous performance measures exist. Financial statement analysis relies on the availability of dollars or dollar ratios to yield its insights. Company analysts commonly speak in terms of return on equity, return on investment, inventory turnover, cash flow, debt to equity ratios, earnings per employee, and changes in these values over time. With respect to information, however, units such as dollars and yen do not come readily to mind. The closest approximation, the binary digit, was proposed in 1949 to indicate the truth or falsity of a single datum and to tie electronic circuits to mathematical logic.[9] Although in 1991 the bit[10] forms the basis of all machine resident information, like the atom, it has the wrong level of precision to be managerially useful; "... the famous definition of information by Claude Shannon and Warren Weaver, who helped found information science, while useful for technological purposes, has no bearing on semantic meaning or the 'content' of communication."[11]

Another difficulty is the problem of establishing a transaction. Whether information is conveyed through reading a printed page, speaking with a supervisor, or processing instructions through a microchip, information sources never experience a loss.[12] Data available to a provider of information is no less available after it has been shared with a second party. Nothing has been consumed. Conversely, given the absence of an information currency, it is difficult to determine

[9]Shannon, Claude (MIT Master's Thesis)
[10]The term "bit" was coined by John Tukey upon hearing hearing colleagues at Bell Labs describe the need to name "binary digits". Penzias '89; p. 99.
[11]Toffler, Alvin; *Powershift*; New York: Bantam Books © Nov. 1990; p. 18.
[12]This may be strictly true only in a quantitative sense. In a qualitative sense, the position of the source may have diminished relative to that of the recipient. For more on "Information Trading" see Schrader '90.

precisely how much the recipient has gained. In an accounting sense, no transaction has occurred that would allow for the rearrangement of assets on a balance sheet. Until a cash or cash equivalent impacts an asset or liability, no change in value takes place.[13]

The conceptual vagueness of information also gives rise to a diversity of opinions on its nature. This lack of consensus leads to problems establishing a consistent set of tools for analyzing and researching it. Various authors have proposed breaking information into types such as numbers, words, and pictures [Penzias '89]; others have proposed attributes such as timeliness [Grochow '72], content [Feltham '68, Lev '72], format [Benbaset and Dexter '85, DeSanctis '84] and cost [Ahituv '80, Kleijnen '80]. Others have borrowed from Claude Shannon's original work in the field of communications and used the entropy function[14] to measure the quantity of information provided by a source describing likely events by their probabilities [Kinchin '57, Lev '69]. Still others distinguish between what the value of information should be -- its normative value -- and its perceived value [Zmud '78, Munroe and Davis '77]. A significant problem, then, is a lack of consensus on how to treat information.

A fourth barrier to successful information management is more philosophical. People tend to consider information, knowledge, and ideas the province of sentient actors, not of unconscious machines.

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[13]In the case of a costly database search, for example, current pricing practice assures that a company incurs a liability based on the costs of searching irrespective of whether the search returns with any information. See DIALOG pricing policies. A two tiered pricing policy will almost certainly emerge -- one for the cost of searching and another for the cost of information -- if an information currency gains widespread acceptance.
[14] $-\sum$ i=1 to n Pi log(Pi) This function is derived in Appendix B.

While recognizing this as an organizational and sociopolitical hurdle, the position taken here maintains that such "sentient-centricity" poses an implementation problem rather than a conceptual one. In fact, whether information resides on hardware or software, in personnel or on paper does not impact the volume of data present. Information's storage media affects its accessibility and the ease with which it may be processed. Information media should not affect its quantity.

Value must be affected by storage media, quantity must not. Whether milk is stored in cartons, cases, or cows, its volume is fixed and finite at any point in time. The storage media do, however, create differences in the associated utilities. Price changes with the storage medium and with the nature of the product. Likewise, information stored in vacuum tubes, transistors, magnetic tape, optical disks, or personnel is fixed and finite at any point in time. Here also, the specific information may change and its value depends on where it is stored and how it is used. The medium determines the manner in which data may be used and the costs associated with extracting and processing it. Information available in staff members is difficult to extract but easy to deploy whereas information in print is easy to extract but difficult to deploy. The distinction between quantity and value must be sharp; quantity dictates the units, while value sets the price.

CHAPTER 2

It is a capital mistake to theorize before one has data.
-- *Sir Arthur Conan Doyle*

Existing Theories of Information Measurement

The need for a theory of information management has been recognized for over thirty years. Others have noted as early as 1960,

> ... there are today no generally accepted criteria ... for deciding what information is needed, how frequently the information is required, how accurate it needs to be, and how the information is to be originated and transmitted.[15]

Existing literature ranges from the theoretical to the practical. A selection of these theories sacrifice accuracy for the sake of convenience, while others forego practical methods in favor of elegant theories. The choice lies in selecting the best balance between virtuous theories and theoretical virtues. No one system has gained widespread acceptance, but the existence of so many theories proves the need for one which works.

To place current literature in perspective, Ahituv's framework classifies systems as normative, realistic, or perceived value.[16] "Normative" theories provide the value of information under ideal conditions. These set an upper limit on information value and provide theoretical bases for its quantification. "Realistic" systems of information measurement attempt to quantify differences in the

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[15]R.M Trueblood; "Operations Research -- A Challenge to Accounting;" *The Journal of Accountancy*; May 1960; p. 50; cited in [Feltham '68].
[16]See Ahituv '89.

performance of information users. These systems define the value of information as the incremental benefit -- the measurable change in results from differences in decision behavior. "Perceived value" systems gather user impressions of performance independent of actual behavior. Of the five information frameworks which follow, the first two represent normative theories, while the third and fourth theories represent realistic and perceived value proposals, respectively. The fifth proposal combines aspects of both the normative and the perceived value approaches.

Information Economics and Decision Theory

The most commonplace theory of information is decision theory, an economist's adaptation of statistical modeling and choice under uncertainty. As McGuire notes:

> ... there is a simple and tentatively[†] widely agreed-upon formal structure, ready-to-hand, namely decision theory, which can serve as the abstract basis [for] investigation. ...[[†] footnote -- By "tentatively" is meant that while not all students of information accept the framework we use here for *all* of their own work, nearly all (statisticians for instance) information theorists know the framework and regard it as suitable for analysis of *some* questions.][17]

Treatments of decision theory vary somewhat in their focus and their formal presentation. The most basic of these, Expected Value of Perfect Information (EVPI), is taught in standard textbooks on statistics.[18] EVPI is measured by the difference in expected profit between a decision made with perfect information and under

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[17]McGuire, C.B.; "Comparisons of Information Structures." in *Decision and Organization*; C.B. McGuire and R. Radner, Eds.; Minneapolis, MN: University of Minnesota Press, Second Ed.; © 1986; p. 102.
[18]Hamburg '87.

uncertainty. A more sophisticated decision theoretic approach, originally proposed by Marschak, has been extended in several useful ways [Mock '71[19], Marschak and Radner '72, Hilton '81]. Decision theory assumes that an information system responds to events in its environment by providing messages, or signals, to a decision maker. Based on an *a priori* set of preferences, the user responds to these messages deterministically to optimize his expected value. The messages cause him to intervene in the world, effecting the most desirable outcomes. The entire system may be described by the following model.

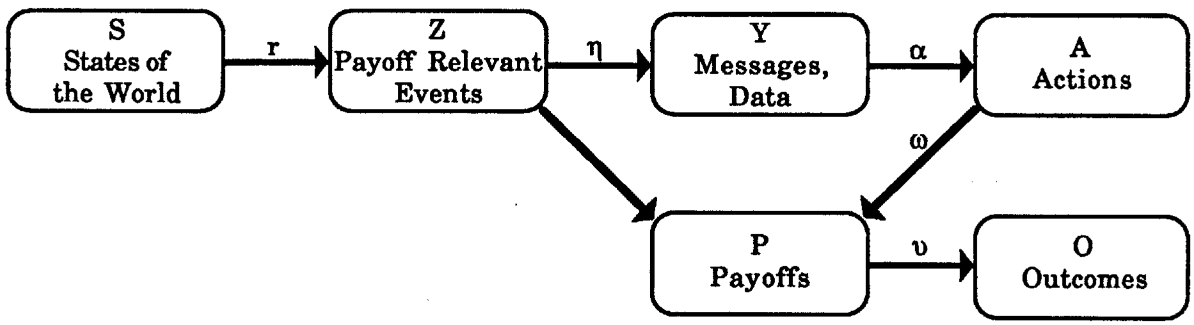

Figure 2.1 -- Information may be characterized by its use to effect payoffs.[20]

S = Universal set of states of the world.	r = A partitioning which distinguishes only those states affecting payoffs.
Z = Set of payoff-relevant events.	η = An information association relating events and messages.
Y = Set of messages (Information) about the state of the world	α = A decision function (rule) relating events and messages.
A = Set of possible actions.	ω = An outcome function mapping actions into effects.

[19]Mock calls this the Economic Value of Information (EVI); see Mock '71.
[20]Diagram adapted from Mock.

O = Set of possible outcomes (one outcome for each Z, A pair)	υ = A utility function relating a payoff (a p_j in P) with each outcome (o_j in O).
P = Set of payoffs (associated with each outcome).	

This model improves on EVPI by accounting for changes in the user's ability to alter outcomes, for discrepancies in the user's ability to recognize states of the world, and for differences in the nature of his preferences. The function below yields the value of information and is developed in Appendix A.

$$\sum_y \sum_s \upsilon[\omega[s, \alpha(y)]]\phi(s \mid y)\phi(y) - \sum_s \upsilon[\omega[s, a]]\phi(s)$$

From these definitions, it is possible to derive several basic principles respecting the determinants of information value.[21] These factors arise from four interpretations of the model's variables.

(1) Flexibility -- Changes in the action set *A* affect the maneuverability of the decision maker.
(2) Wealth, Technology, and Environment -- The capacity for intervention may also be dictated by a decision maker's initial wealth, his technology, and the environment. This is one interpretation of ω.
(3) Degree of Prior Uncertainty -- $\phi(s)$ gives the level of uncertainty (perhaps confusion) of a decision maker regarding states of the world.
(4) Nature of the Information System -- The reliability of the information system and its correspondence to actual states is given by the Bayesian term $\phi(s \mid y)$.

Hilton '71 undertook a summary of theorems respecting the value of information as characterized along these dimensions. The most useful of these is known as Blackwell's theorem. Given a fixed set of

[21] Marschak and Radner '72, Wilson '75, Hilton '81. The following interpretations and summary theorems appear in Hilton.

states S and two distinct information systems providing signals Y_1 and Y_2,, the information provided in the set Y_1 is at least as great as Y_2 if Y_2 is a subset of Y_1. The statement also holds true if there exists some transformation of a subset of Y_1 which maps onto Y_2. Blackwell's theorem represents one of few characterizations of the intrinsic value of information independent of the decision problem. It makes no claims, however, about groups of information in which one group is not completely contained within transformations of the other group. This point will motivate multi-attribute theory in a later section (see page 29). The decision theoretic model unfortunately provides few strong general purpose assertions. This model indicates the impossibility of making strong statements. To summarize:

(1) There is no general monotonic relationship between action flexibility (changes in A) and information value.
(2) There is no general monotonic relationship between the degree of risk aversion and information value.
(3) There is no general monotonic relationship between wealth and information value.
(4) There is no general monotonic relationship between prior uncertainty and information value.[22]

Numerous exceptions exist for these theorems, each with their own special set of preconditions. A thorough search has been undertaken for precisely those conditions under which available options, risk aversion, initial wealth, and uncertainty influence information value. In an independent publication, Marschak[23] begins to account for decision delays and obsolescent information.

[22]Although it is not generally possible to order probability distributions by degree of uncertainty, a useful measure is given equivalently by (i) all risk averters prefer E(S1) to E(S2); (ii) S2 equals S1 plus noise; (iii) S2 has more weight in the tails.
[23]Marschak '71.

Despite these advances and a recognition of their importance, there are three principal difficulties with decision theory. It recognizes no use of information other than for decision making; it assumes a massive amount of foreknowledge; and it focuses on the information setting rather than on the information. Due to the importance of decision theory, each of these problems will be elaborated separately.

Several researchers have recognized that information serves multiple purposes [Mock '71, Zmud '78, Benbasat and Dexter '85, Ahituv '89]. A more complete list of the uses of information was noted in Benbasat and Dexter. In their treatment of the graphical use of information they note that reports may be used for "reading and retrieval of data, communication of facts, comparison of alternatives, trend analysis, recognition and recall, problem finding, problem comprehension and problem solving"[24] to which Mock might add learning and feedback, and measuring efficiency. Importantly, even accepting the assumption that measurement of information depends on measurement of the environment (a point debated in a later section), decisions represent only one form in the pantheon of uses of information.

That decision theory relies on prior knowledge may bear little theoretical significance, but in practical terms it renders the theory inapplicable to most problems of more than academic interest. Deployment of the insights gained through decision theory requires a near complete *a priori* awareness of decision criteria, prior probabilities,

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[24]Benbasat, I. and A. Dexter; "An Experimental Evaluation of Graphical and Color-Enhanced Information Presentation;" *Management Science*, Vol. 31, Num. 11, Nov. 1985; p. 1349.

available actions, and prevailing states of the world. These preconditions have led others to conclude:

> Theoretically, the information economics approach is very appealing; realistically, it appears impractical (if not impossible for dynamic environments).[25]

> The economic value of information concepts, while being derived from a sound logical construct, have not proven to be of frequent value in the design of more effective information systems... a main reason is that the knowledge prerequisite to the calculations is not available.[26]

The third difficulty with decision theory is its detour through measures of the environment to measure the value of information. Environments change and therefore the value of information *must* change according to this system. Given fixed and constant information, its value will fluctuate each time the world changes. No other commodity is measured in this extrinsic fashion. Rather, to each product is assigned an intrinsic measure, giving its objective quantity. Value is subjective, reflecting each buyer's willingness to pay for his needs. Decision theory successfully measures the buyer's needs without ever telling the seller what he owns[27] -- an issue which will be discussed later. The point is to arrive at a measure of information which is constant with respect to changes in the decision environment.

Information Quantity – The Entropy Function

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[25]Zmud, Robert E.; "An Empirical Investigation of the Dimensionality of the Concept of Information;" *Decision Sciences*, Vol. 9 Num. 2, Feb. 1978; p. 188.

[26]Mock, T.J.; "Concepts of Information Value and Accounting;" *The Accounting Review*, Vol. 46, Num. 4, Oct. 1971; p. 770.

[27]Some might argue this point, contending that the value of the owned information is governed by the cost of producing it . While true, the new owner still has little idea *how much* information he owns. A quantitative approach to information appears in the next section.

In the 1940s, Claude Shannon recognized the equivalence of binary representation and the logical algebra of nineteenth century mathematician George Boole. Shannon's insight forged the critical link tying simple on and off relays to the existing body of mathematical induction. This is the heart of digital logic circuitry and it is what enables manufactured devices to perform the fundamental logical operations. Shannon carried his theories a step further, however, borrowing functions from thermodynamics to estimate how much 'information' such a relay or other communication channel might carry. The relevant function for information quantity is the entropy function, shown below and derived in Appendix B. Symbol *p* represents the prior probability of a particular event occurring.

$$-\Sigma_{i=1} p_i . \log(p_i)$$

This measure has been adapted for use in accounting by assuming that the size of any T account relative to the total of all accounts gives a fraction equal to its prior probability [Lev 68, 69]. Application of the entropy function can measure the amount of information loss (or gain) experienced when various accounts are aggregated (or disaggregated) to yield a smaller (or greater) number of categories. The measure works well within -- and in some cases improves upon -- heuristics established by the American Accounting Association for aggregating balance sheet data. The following example illustrates[28]. In the listing of items from a balance sheet of Boston Edison, certain of the items may be aggregated by the category. Which categories may be combined reflects standard accounting practices but,

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[28]Example developed in Lev; 68.

to a large extent, depends on the discretion of the accountant preparing the financial statements. A question arises as to which of the items ought to be combined and which of the items ought to remain distinct.

Figure 2.2 -- Boston Edison Company, December 31, 1963
Assets and Other Debits (Dollars)

1.	Net electric plant in service	327,802,559
2.	Electric plant, construction in process	21,609,430
3.	Net steam plant in service	10,520,537
4.	Steam plant, construction in progress	179,584
5.	Net nonutility property	2,167,063
6.	Other investments	1,758,042
7.	Cash	4,048,773
8.	Special deposits	1,166
9.	Working funds	242,495
10.	Notes receivable	53,004
11.	Customers accounts receivable, net	17,448,883
12.	Other accounts receivable	479,353
13.	Fuel stock	1,218,478
14.	Plant materials, supplies and merchandise	7,176,643
15.	Prepaid insurance	369,210
16.	Other prepaid items	10,028
17.	Rents receivable	40,607
18.	Miscellaneous current and accrued assets	61,032
19.	Unamortized discount series D bonds	41,501
20.	Refunding costs series G bonds	341,875
21.	Temporary facilities	18,249
22.	Deferred debits: Federal income taxes	990,800
23.	Deferred debits: Miscellaneous	321,644
24.	Nonutility property additions	82,193
25.	Sewer use tax	12,037
	Total assets and other debits	396,995,186

A determination is generally made as to the level of significance of the information that would be lost if two or more items were combined. What precisely defines significant? If one allows the amounts of the items to represent the prior probability of information about a dollar allocation, one may interpret the particular asset in terms of the entropy function. Figure 2.3 gives the categories that may be aggregated and the amount of information loss, as determined by the entropy function, that would occur if the categories were represented as one. The total entropy is given by the summation of the entropies of the individual items.

Figure 2.3 -- Analysis of Aggregated Categories

Aggregated Item	Information Loss (10^{-5} bits)	Aggregated Item	Information Loss (10^{-5} bits)
1, 2	29,461	10, 12, 11	837
3, 4	331	13, 14	1,264
2, 4	378	15, 16	17
5, 6	981	17, 18	25
7, 8	4	19, 20	48
8, 9	3	21, 24	17
8, 9, 7	345	22, 23	266
10, 12	63	23, 25	19

The first two categories dominate the amount of information. Although the categories are potentially mergeable, the amount of information lost or obscured by the merge would probably make it impermissable to do so. Note also that the loss from merging 7 with 8 and merging 8 with 9 is quite small, but the merge of all three is not. Generally, the closer two categories are in approximate size, the greater the amount of information lost.

The real benefit of this framework is that given a fixed standard, perhaps a set loss of no more than 5% of the initial information, it becomes possible to automate the process. It also creates interesting comparisons between companies if the balance sheets are restricted to losses of no more than this fixed percent. Quantity of data lost (or gained) may play a decisive role in generating predictable documents.

Entropy measurements work well under specific circumstances. They aid in the ordinal ranking of groups of similar information, where 'similarity' is judged by an independent standard. Entropy heuristics may also be used in the composition of new groupings of information which minimize loss. But, as in the case of decision theory, the conditions require that a complete and accurate set of *ex ante* probabilities are available and known to the user. It also falls prey to one of the criticisms of decision theory, namely that users lack the omniscience to fully characterize existing states of the world. In the accounting example, fractions of a previously recognized total stand as surrogates for prior probabilities and therefore give a complete description of prior probabilities. Many practical problems do not afford this opportunity.

Difficulties also arise in broadening the applicability of entropy theory to other types of problems. Shannon originally intended to measure only channel capacity, never semantic content. Divorced from meaning, the 'bit' is a difficult unit on which to base estimates of value. In their seminal treatise defining information theory, Shannon and Weaver note that "the word *information*, in this theory, is used in a special sense that must not be confused with its ordinary usage. In particular, information must not be confused with meaning."[29] Efforts to measure value through entropy

> ... usually confront a deficiency inherent in the entropy function: the function does not account for meaning of the events but only for the probability of their occurrence ... it appears that the use of entropy as a measurement for data quantity may be effective, but its use to measure the value of information is quite limited.[30]

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[29]Shannon, Claude and Warren Weaver; *The Mathematical Theory of Communication*; Urbana, IL: University of Illinois Press; © 1949; p. 99.
[30]Op. Cit., Ahituv '89 p. 317.

After an investigation of entropy's relationship to perceived value, Ronen and Falk found that specialized use of the entropy function was valid but:

> from a theoretical viewpoint, it seems that the entropy measure cannot be suggested as a *general-purpose* surrogate for the value of information.[31]

Additional intellectual paradigms are necessary to gauge information value. The following approaches seek to achieve this through a shift to more applied techniques.

Realistic Value of Information

The realistic value of information approaches tend to be empirical and heuristic rather than quantitative. That is, after testing the performance of decision makers in a controlled situation, experimenters determine the value of information inputs and summarize results as guidelines for the construction of decision support systems. For example, "Subjects receiving summary data (in contrast to raw data) had lower total production costs (made better decisions) but took longer to make their decisions and had lower confidence in the quality of their decisions."[32] Actual measurement proceeds by measuring user performance at the end of the information usage chain.

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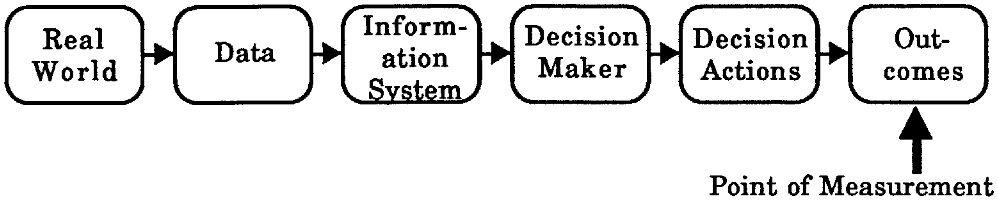
[31]Ronen, J. and G. Falk; "Accounting Aggregation and the Entropy Measure: An Experimental Approach;" *The Accounting Review*, Vol. 48, Num. 4, Oct. 1973; p. 697.
[32]Dickson, et. al.; "rResearch on Management Informaiton Systems: The Minnesota Experiments;" *Management Science*, Vol. 23, Num. 9, Sept. 1977; p.919.

Figure 2.4 -- Realistic value measurements examine actual outcomes.[33]



In these studies, the researchers examine a threefold relationship existing among a decision, a decision maker, and an information system. The 'decision' affects the context and ultimate value; the 'decision maker' determines the user's disposition towards applications of information and his approach to problem solving; and the computer 'information system' affects the quality of the information conveyed. The most noteworthy series of studies have come to be known as the Minnesota Experiments, summarized by Dickson, Senn, and Chervany. The tests took the form of experimental games in which the value of one characteristic of the threefold relationship could be assessed by varying the test conditions. A few of their findings include:

(1) Subjects receiving summary data rather than raw data make better decisions but are less sure of their choice.
(2) The ability to customize reports improves decision making capability.
(3) Cognitive factors (risk aversion, quantitative aptitude, previous experience) may correlate positively with decision outcomes.
(4) Goal setting improves performance.
(5) The more timely information of interactive over batch systems improves performance.

In a separate series of experiments, Mock tested the performance of decision makers under two conditions; one group received real-time information while the other received lagged information. Charts of actual performance indicate that the real time group had wider swings

[33]Diagram from Ahituv '89; p 320.

in their behavior but, on average, tended to have slightly higher profits. Importantly, however, both groups used information in a feedback sense. Final performance greatly exceeded initial performance for both groups, indicating a different type of information use, namely learning.

The format of information presentation is the subject of a literature review by DeSanctis[34] wherein he examines the effect of presentation on the decision maker. Reviewed experiments tested the effectiveness of graphs versus tables, color versus black and white, and great versus modest detail. Researchers judged the success of a particular format according to the level of recall, the time to reach a decision, comprehension, viewer preference, and decision performance. Several "premises" emerged as guidelines for the construction of information systems. A few observations concerning information format which were expressed in the literature include:

(1) Color may increase attention to a visual but rarely enhances comprehension.
(2) People prefer and will more successfully recall visuals which more accurately reflect the features of a particular problem.
(3) Simplicity increases comprehension.
(4) Evidence suggests that graphs are no better than tables; the optimal format depends on the problem.
(5) The ability to use a specific format varies with individuals.

The realistic approaches to information measurement tend to correlate reasonably well with the normative values which yield theoretically correct values in dollar terms. This approach is not without problems, however. There are caveats and exceptions, and

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[34]See also Benbasat and Dexter.

particular findings pertain only to particular decisions. Given the variety of success criteria, it is not surprising that some experiments have led to conflicting results.

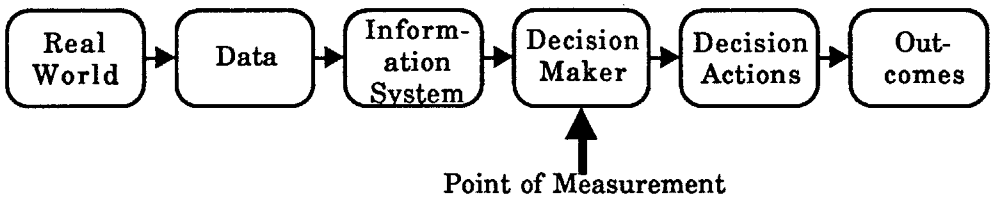
A particular difficulty reflects the problem of taking accurate measurements. As illustrated in the information chain of Figure 2.4, the distance between the source of data and the actual outcome is quite large. This distance represents what the realistic approaches attempt to measure and it introduces several sources of variability -- the idiosyncracies of the decision maker, of a particular working software package, and of restrictions on the available actions -- which have nothing to do with the value of the actual information.

The realistic approaches, having been designed to apply the decision theoretic approaches, suffer from similar criticisms. Their results depend on a specific problem and consequently test only for extrinsic information qualities. Advocates of the entropy function and of multi-attribute theory (developed in a subsequent section) recognize the importance of attributes such as quantity which transfer across contexts.

Perceived Value of Information

Results obtained through perceived value approaches parallel those of the realistic approaches in that both are largely empirical. The perceived value of information is determined by querying the decision maker about the value of the information he receives.

Figure 2.5 -- Perceived value measurements survey decision makers.[35]



Experiments to test perceived value may ask managers their opinion of information, a soft estimate of value. A more sophisticated approach is to request the maximum amount a manager is willing to pay for information, indicating the demand price, or to request the minimum amount a manager is willing to receive in lieu of information, indicating the supply price.

Studies of the monetary equivalence or willingness to pay concluded,[36] however, that the perceived value of information did not correlate well with normative measures except to the extent that users were informed of prior probabilities. Surveys of managerial satisfaction with information systems and information attributes found that the information provided was generally useful and appreciated.[37] Other authors surveyed managers with respect to various information attributes, finding that certain attributes were preferred, for example, relevance, accuracy, quantity, reliability, and readability[38]. These attributes fell into four broad categories corresponding to quality, relevance, format, and meaning. The utility of presentation formats also appears in literature covering the realistic value of information.[39]

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[35]Ibid.
[36]Ronen and Falk '73.
[37]Adams '75.
[38]Zmud '78. Two other features, factualness (truth) and reasonableness, seem fairly indistinguishable from these six features. Adams '75 examines a similar set of features.
[39]DeSanctis '84.

Efforts to quantify these attributes appear in the following section on multi-attribute theory.

Differences between the optimal value and the perceived value of information create measurement problems. Potential explanations have suggested that users "satisfice" -- that is, individuals may seek to find a minimally acceptable solution in lieu of a potentially expensive (in effort) optimal solution[40]. The subjectivity of the perceived value approaches, however, makes them suspect as a basis for developing units of measurement.

The best use of perceived value is not as a unit of measure but as an index of user satisfaction. Untrained users may misinterpret the essential features of information, but information systems which cater to user perceptions tend to win their favor. Although this carries little significance for information theory, it plays a critical role in information system design.

Multi-Attribute Utility Theory

Between the sterile canons of decision theory and the managerial oversimplifications of perceived value systems, intermediate ground exists. Multi-attribute theory begins to quantify the features of information which users find valuable. Various authors have proposed quantifiable dimensions of information. Feltham '68 considers relevance, timeliness, reporting delays, and accuracy. Ahituv '80 attempts to measure content, format, timeliness, and cost. Barua et alia '89 introduce useful mathematical interpretations of signal timing, reporting frequency, monitoring period, signal resolution, intrinsic

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[40]Newman '80.

accuracy, and intrinsic informativeness. These last three attributes are based primarily on Blackwell's theorem regarding the aggregation of data and the transformation of one group of signals into a smaller subset. As used in the Barua article, these terms relate more to levels of detail than to "accuracy" or "informativeness" as commonly understood. The literature indicates no widespread agreement has emerged on a core set of representative attributes. A few examples of the more interesting attribute definitions introduce representations of an inchoate system of information measurement.

Relevance: Without offering a specific mathematical interpretation, Feltham discusses two versions of "relevance". The first *ex post* definition is that "if a signal changed the decision, then the information provided by that signal was relevant."[41] Rejecting this definition as unhelpful at the time of the decision, he proposes an *ex ante* definition in terms of the information system itself. He proposes that a change to the *system* be considered relevant if, for some of the events which might occur, "some of the signals will be different, and some of these differences will lead to differences in the decisions made."[42] A mathematical representation of relevant changes to the information system might then be given in terms of the probabilities of changed decisions.

Content: Ahituv proposes the similarity of two data sets as a measure of their information content . For any given decision, Ahituv assumes that an ideal set of signals Y^* may be determined whereas the

[41] Feltham, G.A.; "The Value of Information;" *Accounting Review*, Vol. 43, Num. 4, Oct. 1968; p. 691.
[42] Ibid.

actual set of signals provided by an information system is Y. For the two data sets, there are three potential classifications of Y's intersection with Y^*.

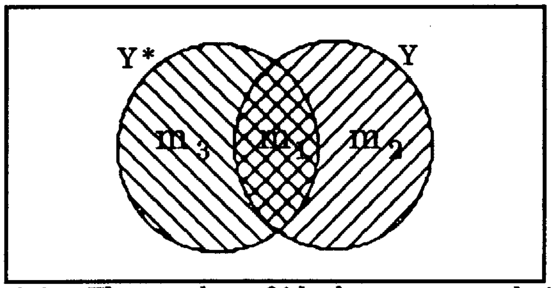

Figure 2.6 -- The overlap of ideal versus actual signals.
Set m_1 -- Y provides exactly what is in Y^*.
Set m_2 -- Y provides excess signals irrelevant to Y^*.
Set m_3 -- Y omits signals pertinent to Y^*.

On this basis, the level of similarity is defined as:

$$S = \frac{|m_1|}{|m_1| + |m_2|} - \frac{|m_3|}{|m_1| + |m_3|}$$

The scale of similarity ranges from -1 for completely unrelated information to 1 for identical information. For disjoint sets, ($|m_1| = 0$), S is at its minimum of -1. For completely overlapping sets, ($|m_2| = |m_3| = 0$), S reaches its zenith. Two other possible cases are Y is a subset of Y^*, ($|m_2| = 0$; $|m_3| > 0$), for insufficient information and Y is a superset of Y^*, ($|m_2| > 0$; $|m_3| = 0$), for excess information. In these cases, $-1 < S < 0$ and $0 < S < 1$ respectively.

As in the two preceding cases, a majority of proposed attributes still suffer from the same criticisms as the decision theoretic approaches they are intended to augment. Attributes that rely on the decision context change in value with changes in the environment and they require a foreknowledge of prior probabilities. They rely on payoff-relevant as opposed to cost-relevant details. Barua summarizes:

> ... confusion exists in a section of the evaluation literature due to mixing of intrinsic and extrinsic attributes and decision characteristics... While intrinsic attributes can be compared for two [information systems] without reference to a decision context, it is not meaningful to use extrinsic attributes as dimensions of information [value].[43]

Accordingly, Barua et alia develop intrinsic attributes. A few examples follow.

Signal Timing: The point in time when a decision maker receives a signal is defined as the information system's signal timing. If the action set A of the decision maker changes over time, then intrinsic signal timing will impact the value of the signal. In particular, if the number of options is declining, namely $\partial A / \partial t < 0$, then earlier information is more valuable. On the other hand, if the action set remains constant, then the value of timeliness is zero.

Signal Resolution: Applying Blackwell's ideas, an information system IS_1 is said to possess higher signal resolution than IS_2 if the signals produced by IS_2 are a subset of the signals produced by IS_1, i.e. $Y_1 \supseteq Y_2$. For example, IS_1 might include data on demand, inventory, and prices whereas IS_2 only reports on demand and inventory. Resolution may also refer to data aggregation such as from daily to monthly demand. On this basis, it becomes possible to demonstrate costs associated with lower than adequate resolution.

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[43]Barua, et al.; "MIS and Information Economics: Augmenting Rich Descriptions with Analytical Rigor in Information Systems Design;" *Proceedings of the 10th International Conference on Information Systems*, Dec. 4-6, 1989; p. 330.

Let the state of the world be such that prevailing demand in two areas takes on only two values, s_1, $s_2 \in \{100, 200\}$ and further allow the cost function to be given by $z(a_1, a_2, s_1, s_2) = 4(a_1 - s_1) + 6(a_2 - s_2)^2$. The potential states of demand are characterized by (s_1, s_2) = (100, 100), (100, 200), (200, 100) or (200, 200). Now assuming that an information system has the ability only to report aggregate demand, it reports only y_i = {200, 300, 400}. Given aggregate reporting on states (100, 200) and (200, 100) the only appropriate action is to assume $a_1 = a_2 = 150$. The cost of this imperfect assumption is $4(150 - 100) + 6(150 - 200)^2 = 15{,}200$ or $4(150 - 200) + 6(150 - 100)^2 = 14{,}800$. Had the signals provided adequate resolution, the costs would have remained at 0. Lower than adequate resolution may therefore be shown to have negative value. On the other hand, higher than adequate resolution may also be shown to carry additional cost since additional information processing is required to reduce it to the payoff-relevant level.

General Observations on Existing Theories

Ahituv asserts that information and data are different -- "knowing the price of gold tomorrow is very valuable, while knowing the price of gold a year ago is an unimportant piece of data"[44] While true, the same may be said of any future resources that are deployed ahead of their time. Anyone owning a modern supercomputer a century ago would dominate the world of computation-intensive problem solving and would enjoy the economic benefits such capabilities would grant. Owning that same computer a century into the future would be no more

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44 Ahituv, Niv; "Assessing the Value of Information: Problems and Approaches;" *Proceedings of the 10th Annual International Conference on Information Systems*, Dec. 4-6, 1989; p.315.

valuable than owning a slide-rule in the company of a personal computer. In fact, this example does not distinguish information as unique from other resources. Rather, it demonstrates the principle of scarcity. Were it the case that other market participants also knew tomorrow's price of gold, the value of this information would decrease in proportion to the number of people who owned it. Information, like gold, also derives its price from scarcity. If gold were as common as sea water, economics dictate that it would carry a similar price. In order to prove information singularly idiosyncratic and difficult to measure, the important question is not to identify issues which make measuring information difficult, but to identify issues which set it apart from other resources which do not face similar problems in their measurement. This essay contends that a comparison of information to other resources shows such differences to be rare.

A similar assertion is that "...the value of information cannot be separated from the value of an information system for exploiting the information."[45] The supporting argument suggests that if an individual possessed of tomorrow's price of gold were marooned on an island, then the value to its owner is negligible. Without the means of exploiting knowledge, the value to its owner falls to zero. Again, this assessment of value rings true. But again, the claim is equally true for other commodities. Without the means to exploit it, the value of a gold ingot falls to zero. In fact, all resources are valued by the processes which extract, produce, or manipulate them. The implications for resource value, however, are completely independent of the implications for

[45]Ibid.

resource quantity. Fortunately, it does not follow that information quantity may not be separated from the mechanisms which process it. To add concreteness to this example, one might consider the fall in the price of gold with the 1890 introduction of the cyanide extraction process. The new process increased the yield of gold per ton of crushed stone and decreased the cost relative to the prevalent mercury extraction process. Likewise, the relative cost of producing agricultural products declined with the invention of chemical fertilizers, the invention of better pesticides, and the development of improved transportation systems. When purchasing a sack of flour, one also implicitly pays for the nitrogen, the malathion, the truck and equipment used to process it.

This does not prevent one, however, from establishing a price for five pounds of flour, nor do similar arguments necessarily prevent one from establishing a price for five units of a given type of information. As in the previous example where scarcity affects the price, processing will also affect the price. But, these problems are not unique to information and focusing on them is to seize upon the wrong set of issues. One must examine that which is unique to information; move from these unique attributes to a unit of measurement; then submit these measures to the market to establish what the market is willing to pay per unit.

In general, most existing information taxonomies would fail what will be called the Phone Book/Physics Text test. The test is proposed as follows. Given 200 pages from a college physics text and 200 pages from a telephone directory, and having translated these writings into the format native to an information taxonomy, can that taxonomy make any useful statements about their relative information quantities or values independent of any specific decision context? If it cannot, then the applicability of the theory to managerial decision making is likely to be limited. The reason for posing the problem "independent of any specific decision context" is to force recognition of intrinsic as opposed to extrinsic value. It is possible to construct pedagogical examples in which the "information" provided by the phone book is more useful to a specific decision and hence, in context, more valuable. This yields a strictly contextual value. This essay, however, seeks to disclose and clarify an intrinsic rather than contextual measure of information. The normative approaches to information assessment generally have little to say about information devoid of context. The perceived value (or subjective) approaches, on the other hand, correlate badly with the normative approaches, making it almost impossible to measure information objectively.

Quantity and value, although related, are orthogonal concepts. A thousand board feet of knotty pine and an equal amount of black walnut will construct the same number of shelves, but the prices charged will be very different. Increased quantity need not connote positive value; if the "product" is toxic, *more* brings the producer *less* income. Price reflects value as distinct from quantity, and a variety of attributes must enter into a market's determination of utility. Constructing a theory of information quantity assessment requires establishing units of information as well as the attributes from which a market may determine a price.

CHAPTER 3

> Because a skeptical questioner had stumbled on the right question, pertinent information emerged from the mass of stored data. -- *Arno Penzias*

Proposed Theory -- Definition of Information Quantity Assessment (IQA)

In response to the information investment questions posed in the introduction, this section develops a classification framework to cover attributes and measurements.

This information taxonomy seeks to provide a language for making strong statements about defined classes rather than broader but weaker inferences. Weak or generic guidelines have little value; superficial theories lack actionable conclusions. Managers cannot base decisions on abstract generalities. Categorizing information, on the other hand, allows one to examine different mechanisms for creating value for different types of information. The hierarchy proposed here divides information into these categories: description, instruction, and principle.

Definition of Terms

Description: This class of information contains historical facts. These are data which communicate times, locations, amounts, personnel and other details which record the past and present activities of a firm. Examples include scanner data, mailing lists, inventory records, and tax receipts. For measurement purposes, the unit of description is the "relation," adapted from relational database terminology.[46] "The term *relation* is used here in its accepted mathematical sense. Given sets S_1, S_2, ..., S_n (not necessarily distinct), R is a relation on these n sets if it is a set of n-tuples each of which has its first element from S_1, its second element from S_2, and so on. We shall refer to S_j as the *j*th *domain* of R."[47] In a spreadsheet of **m** rows and **n** columns, the number of relations is **m**, the number of domains is **n** and the number of total data points is **nm**.

Instruction: Processes, the second class of information, are sets of instructions providing sufficient detail for an agent to execute the steps of a plan. If *description* addresses the details of "who," "what," and "how much," then *instruction* addresses the details of "how." For physical processes, instructions indicate the physical translation or transformation to be performed on inputs to production. Examples of instructions include the steps in an assembly line or the steps in servicing a part. In addition to physical instructions, there are conceptual instructions such as the mathematical operators. The number of steps in a process gives its quantity of measure. Each instruction changes the state of a description.

"Instruction" was chosen to describe this class of data since it does not imply a whole "process" nor does it necessarily suggest a "purpose." One instruction is a single atomic step. The name suggests intervening

[46] Although implementation issues will not be dealt with in detail, a few observations should be noted. In general, anything that may be represented in a database may be stored as the value for an observation. For practical purposes, however, the observations are assumed to be numeric. Even non-numeric data may be represented numerically so long as they comprise elements from a countably infinite set.
[47] Op. Cit., Codd '70; p. 379.

in the state of a physical or conceptual world to change the description which characterizes it.

The dichotomy present in an expert system database represents a useful analogy. Expert systems typically contain both declarative and procedural data. The declarative data may be compared to descriptions and the procedural data to instructions. Rather than a one to one correspondence, however, the facts and rules in an expert system database frequently contain multiple descriptions or steps respectively. The inference engine or driver of an expert system also contains instructions. The inference engine, however, contains implicit rather than explicit steps and it tends to be less accessible to the users than is the rulebase.[48]

Principle: The third class of information deals with properties of data. Principles represent information applied to itself. Under this system, there are two types of principles, *formulae* and second order descriptions or *characterizations*. A formula (or correlation) is defined by a pairwise association of two or more descriptive domains in which one of these domains is the dependent variable and the others are independent variables. Formulae include the intercepts and coefficients which approximate the dependent domain. Importantly, formulae do not assume any causal relationship between sets of highly correlated descriptions. A characterization, on the other hand, gives a description of a domain. Representative examples are its range, its mean, and its

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[48]Interactions would be implemented as 3-tuples. The first element represents an initial description (a relation), the second is an operation, and the third is a final description. (Spanning algorithms exist, any complex process may be defined if the initial and final descriptions are allowed to be multiple relations)

standard deviation. In either case, the appropriate measure of this class of information is the number of principles actually maintained. A combinatorial explosion of principles is possible from any growing database of descriptions but the number of principles will grow only with the number of correlations actually drawn.[49] Formulae and characterizations are statistical analyses of descriptive data.

There are two reasons for the definitions proposed in this classification model, or Information Quantity Assessment (IQA). One of these is to eliminate the subjective bias which computers find difficult to manipulate. Machines poorly handle "gut feel," "intuition," and experience-based bias. Measuring quantity permits the derivation of objective measures of information, which in turn enables computers to manage it. Context sensitivity and causality are specifically excluded from the framework. Nevertheless, as will be demonstrated, the criteria of objectivity and computability leave considerable room for meeting subjective tests of value.

The existing information economics approaches are theoretically capable of being run on computer, but as a practical matter, the unavailability of prior probabilities makes this all but infeasible. The non-quantitative approaches, on the other hand, do not provide either the units or the objectivity which would permit their encoding into software. IQA provides both units and objectivity.

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[49] The implementation of principles would be the same as that for descriptions. Elements of a relation for domain *i* might be (lower bound, mean, domain *i* x domain *j* correlation, ...)

Since statistical operations and quantity measurements are programmable, applying the IQA framework to quantify information enables a computer to become a more sophisticated information processor. The quantity-based framework provides a stepping stone to measurements of value. More sophisticated design work, process enhancement, principle manipulations, and determinations of information management efficiency become programmable. The framework facilitates computer performance of functions which are generally associated with white collar labor.

The second point, and single greatest improvement on existing information frameworks, is that breaking information into classes provides an intrinsic element of semantic content. One criticism of the entropy function is that the "bit" is devoid of meaning. Unable to measure semantic content, logarithms and prior probabilities hold little value for aspiring managers of information. Segregating information by its function gives a measure of its utility based on how it can be used. Descriptions are provided as a means for identifying states of the world. Instructions provide a means of changing from one state to another. Principles govern behavior and provide the criteria for selecting desirable descriptions and desirable instructions. Information's function implies content. By forcing an examination of information function, IQA provides a closer approximation of information meaning. No existing theory of information attempts to approach information through its class or function.

Attributes

Useful dimensions for evaluating information utility emerged from the empirical research on information attributes. Managers offered strong opinions on features that they found valuable. Unfortunately many of these attributes were not intrinsic features while others were not defined in terms of specific numerical indices. This prevents one from comparing bodies of information across contexts. Zmud, for example, provides an excellent set of attributes but without indices, while Ahituv provides attributes which are dependent on the context.

Focusing on classes of information makes the measurement of attributes simpler since the nuances of a specific attribute may change with the information function. The units proposed for classes of information are the number of relations, the number of instructions (or process steps), and the number of principles, respectively. The attributes which affect value may be interpreted differently according to the class of information to which they apply. The definitions provided below consider the class of information relevant to providing numerical measurements. Eight attributes are proposed here: redundancy, completeness, exhaustiveness, novelty, accuracy, time, interest, and relevance. The interpretation of an attribute varies with the class of information to which it applies. (A table summarizing these attributes appears on pages 47-48.)

Redundancy: As it concerns descriptions, redundancy addresses the degree to which a set of relations are unique within a given database. Duplicate descriptions have little value for the owner and in fact may increase the cost of processing descriptive information. Redundancy of instructions measures the extent to which different steps or collections of steps achieve identical final descriptions from identical initial descriptions. This indicates the number of choices one has in choosing how to move from one state to another. Whereas redundancy of descriptions may be harmful, redundancy of instructions may be useful since they represent an expanded set of choices. As in the case of description, the redundancy of principles measures the percentage of duplication. The opposite of redundancy is uniqueness.

Completeness: For descriptive information, completeness measures the number of orthogonal axes recorded in distinct domains. The greater the number of different types of domains included in a description, the greater is its completeness. The presence of domains which may be derived from other domains does not contribute to a more complete description. Similarly, the number of orthogonal axes maintained gives the completeness of the set of principles.

With respect to instructions, completeness measures the percentage of atomic instructions from an overall process which have actually been specified. In a chain of instructions, it indicates how many links may be missing. The value of a process may be negligible unless the complete set of instructions or steps which comprise it are known. It is not uncommon, for example, for software companies to distribute demonstration versions of their packages with a few critical instructions disabled. The entire set of instructions for the process is therefore incomplete.

Exhaustiveness: Whereas completeness measures the thoroughness of information *across* dimensions, exhaustiveness measures the thoroughness *within* a dimension. For description, exhaustiveness measures the number of available relations as a percentage of the total possible relations. This might be, for example, the percentage of published numbers in a telephone directory which if exhaustive would contain both published and unpublished numbers. For principles, exhaustiveness also measures the "fullness" of a particular domain.

For processes, exhaustiveness describes the number of available instructions as a percentage of known instructions. Here, the difference between exhaustivness and completeness is that exhaustive instructions include all members from a set of arbitrary commands whereas complete instructions include all the ordered members in a contiguous chain which accomplishes a specific task.

Novelty: Ubiquity and novelty define opposite ends of a spectrum of values ranging from 0 to 1. The scale may be viewed as the percent novelty and is defined as the inverse of the number of databases which share any of the three classes of information. In other words, if there exists only one database which contains a unit of information then it is completely novel and is represented as 1 or 100%. If, on the other hand, a database were infinitely shared or duplicated, then it would be completely ubiquitous and is represented as 0. Novelty must be distinguished from uniqueness. Information is unique if it appears only once in a database while it is novel if it resides in only one database.

Accuracy: For both descriptions and principles, accuracy measures the degree to which the recorded values match actual conditions. For example, a customer mailing list may be 100% accurate at the time a company compiles it. After a time, a fraction of the names on the mailing list no longer correspond to the locations where the customers may be reached. Likewise, the addition of new observations to a set of descriptions will change the accuracy of the principles associated with them.

For instructions, accuracy translates to yield. This indicates the fraction of times that execution of a specific instruction will achieve the final state. Correspondingly, the accuracy of a chain of instructions, or the yield of a process, is the multiplication of the yields of each of the individual steps.

Time: For descriptions and principles, time provides the instant when the information was first recorded. This provides a means of discovering the age of a particular state of the world. For processes, which create transitions between states, the attribute measures elapsed time. This is the duration of a single instruction or a series of instructions.

Interest: The level of interest for information provides a measure of its anomaly with respect to related information. The measure of relevance of an observation is its deviation from the norm as captured in the principles which describe its domain. In this way, all initial observations are "relevant" or interesting, since there is no established norm, as are all observations that fall beyond a few standard deviations once several observations have been recorded. The "interestingness" of a particular observation will grow or diminish depending on whether succeeding observations fall closer to or farther from the mean respectively. This definition serves to perform anomaly detection.[50] No

[50] This technique is used in Coverstory, an expert system which searches for "interesting" behavior in large databases of UPC scanner data. [see Little '88]

measure of anomaly for principles has been established and therefore the interestingness of a particular principle is not defined.

The interestingness of a process corresponds to the constancy with which it executes. This is also defined in terms of standard deviations but may apply to several other attributes. Interest, in this case, may be the standard deviation of the accuracy (yield) or of time (duration).

Relevance: This implies a measure of goodness or interest but it only has meaning in an implied context. The difficulty with this attribute lies in giving it a mathematical significance which maintains the properties of objectivity and computability for the system of information as a whole. Relevance is therefore defined as follows.

To provide a context, relevance for an operation or process is defined in terms of two arbitrarily complete descriptions. The measure of relevance gives the percent distance that a single instruction moves the values of an initial description towards the values of a final description. A description of completeness five would have five variables each accounting for 20% of the relevance. Variables with initial descriptions equal to their final descriptions may be dropped from the calculations. Instructions may be relevant, irrelevant, or even negatively relevant if they move the initial conditions away from the final conditions.

For descriptions and principles, the measure of relevance is the number of domains which match the domains bearing on a decision problem. This will be determined by a decision maker and is the only attribute which is defined for an external context. It simply provides a mechanism for restricting information to the information subset useful in a decision theoretic sense.

Trends: Additional information value is given by changes in these eight attributes over time. If the accuracy decay rate is high then the subjective value implied by this objective measure will likely be reduced. From an age and a deterioration rate, one may easily determine the date when a set of descriptions becomes valueless or when the yield on a process will be so low as to render it unprofitable. Rates of attribute change provide a ready mechanism for secondary attributes. "Durability" of information, for example, may be defined in terms of the accuracy decay rate.

Figure 3.1 -- List of units of measure and attributes by class.

Quantity	**Description**	**Instruction**	**Principle**
Units	The number of relations; integer.	The number of processing steps or instructions; integer.	The number of relations or formulae; integer.

Quality	**Description**	**Instruction**	**Principle**
Redundancy	Fraction of duplicate relations; percent.	Fraction of alternative instructions which the achieve same effect; percent.	Fraction of equivalent relations or formulae; percent.
Completeness	For entire description -- the number of orthogonal dimensions; integer. For one dimension -- the fraction of relations with recorded data; percent.	Defined for a process or chain of instructions -- the fraction of instructions actually specified from a set defining a process; percent.	The number of dimensions whose values may be characterized or predicted to an arbitrary level of confidence; integer.
Exhaustiveness	For a domain within a description -- the fraction of relations from the total number possible; percent	The fraction of instructions familiar relative to the number known; percent	For a domain within a principle -- the fraction of relations from the total number possible; percent
Novelty	The inverse of the number of owners of this data; range 0 to 1.	The inverse of the number of owners of this data; range 0 to 1.	The inverse of the number of owners of this data; range 0 to 1.

Accuracy	The degree to which recorded values match actual historical values; percent.	The instruction yield; percent. (Process yield is the multiplication of each instruction's yield)	Confidence level; percent.
Time	The recording date of the description; time.	The duration of the instruction; time. (Process duration is the sum of each instruction time)	The recording date of the principle; time.
Interest	Distance from the norm for a given dimension; standard deviation.	Instruction interest is the yield distance from average yield or time distance from average time; standard deviation	Not Defined.
Relevance (defined extrinsically)	The number of dimensions bearing on a decision problem; integer.	The fraction of the distance achieved from an initial description to a final description, averaged over the number of affected dimensions; percent.	The number of dimensions bearing on a decision problem characterized by a principle; integer.

Assumptions

• *There exists, or one may define, an information currency (quantity).*

• *Quantity is the requisite for determining value.*

• *To determine information quantity, it must be treated just as one would treat other valuable commodities.*

• *From quantity, the market will determine value.*

IQA Use and Characterization

The definitions above address the issues which explain the lack of widely accepted information valuation techniques. The quantification of units of information and of those attributes which characterize it defined in the previous section may serve as the foundation for an information currency. If information is to function as a commodity for which a price may be set, buyer and seller must know the quantity of information to be exchanged. The lack of consensus on measures of information stems from an attempt to measure it subjectively in the context of a specific decision. By focusing on intrinsic rather than extrinsic features, it becomes possible to derive objective measures which remain constant with respect to different decision contexts.

From the definition of units, one may also define a transaction. Once an information asset has been quantified, a transaction occurs when any unit of information changes hands. Although the seller may not necessarily lose information, the buyer gains a measurable increase in one type of asset. Regardless of whether the buyer has a specific use for the quantity of information purchased, he will be able to convert it to other types of assets by relinquishing ownership to a third party (and destroying his own copy) so long as the market has agreed upon a fair price for the transaction. The remaining impediment to developing metrics involves a distinction between types of information media. The most reasonable strategy is to account for these differences through the costs associated with encoding and using information resident in different media. Although important, cost issues are orthogonal to issues of quantity. Any finite medium can contain no more than a finite amount of information at any point in time.

When units and classes of information have been defined, bodies of information can be related to one another in order to assess efficiencies of information use. Accounting provides indices of corporate health by various measures of solvency, efficiency, and profitability. These categories can be applied to information as well, although careful interpretation is required; all ratios are relative rather than absolute. Inventory turnover for a heavy industries manufacturer will be markedly different than for a retailer. Three indicators of information health are defined as follows. *Information solvency* measures whether there exists sufficient information to operate. Solvency, in this case, measures how much information is on hand or is at least accessible for use. *Information efficiency* indicates the degree to which information is well used. Although typical measures of efficiency may relate the quantity of a good produced relative to the quantity of resources consumed, the nature of information makes this difficult; information is never destroyed. Tests of leverage, however, may still apply. Information efficiency measures quantity of information output in terms of quantity of input. *Information profitability* measures how much information is produced. Whereas solvency describes the quantity available, profitability describes the rate of new information generation. Marginal information generation ought to be high enough to ensure adequate new information to invest back into the business. As with basic economic profitability, the nongeneration of new information indicates a stagnant operation. One index may portend the other.

Numeric indices make information ratios possible. A straightforward measure of solvency is given by the quantity of each class of information available for use. Treated as simply another resource, a supply of information must be included in inventory in the form of descriptions, instructions, and heuristics adequate to commence operations. Analysis of the relative proportions of each information class could indicate the health of a business. The percentage of recently redesigned processes and of new principles generated may serve as rough indicators of white collar productivity -- one measure of efficiency. Once information becomes a recognized commodity, the level of information output may be used as a measure of productivity. Recognizing information as a commodity, a manager might measure potential waste, losses due to the non-capture and non-storage of information. A manager might also measure information leakage, the amount of data generated by his organization which is simply given away with unrealized revenue. The distribution of financial documents to nonshareholders represents a good example. Information profitability may depend on recently generated formulae. If old formulae remain in use when the underlying data have changed, cash profits may decline. The appropriate relative proportions of each information class must depend on the nature of the business, and the search for new principles ought to be planned, not randomly sought. Measures of information solvency, efficiency, and profitability represent research topics of considerable potential.

Despite its emphasis on quantity, the IQA framework carries implications for information value as well. Precisely defined objective measurements often lead to clearer understanding of seemingly subjective value judgements. For example, one telling criticism of most information measurement schemes concerns their inability to account for obsolescence. Knowledge frequently becomes obsolete with the emergence of superior knowledge which detracts from established value. The issue of identifying obsolete information, however, may be changed into a question of identifying obsolete information by class. Obsolescence of descriptive information implies that a given description has been supplanted by a more recent or more accurate description -- the underlying world state characterized by a description has changed. But this may be directly measured by the description's *accuracy*. The apparently subjective interpretation of obsolescence receives a full accounting under the objective IQA framework. A similar argument applies for principles. For a principle to become obsolete, one of two conditions must exist. Either the underlying descriptive information characterized by the principle has changed -- its accuracy has diminished -- or a new principle has been discovered which has a higher confidence level. Establishing the current accuracy of a principle may require a reexamination of the underlying description. But, in either case, a comparison of the accuracies of the existing and newly discovered principles will serve to expose obsolete information.

Instructions and processes do not become obsolete in the sense that their initial or final descriptions have changed. Rather, a process becomes obsolete because it loses in a comparative value test with a more efficient process. The attributes of an information quantity assessment serve to capture the relative values here as well. Compared to the more efficient process, the obsolete process will score less well on one of the axes of time, number of steps, completeness (which would reflect a new type of instruction), or yield per unit of input (accuracy). Subjective judgement criteria may be interpreted through objective tests if the details of the criteria are sufficiently specific to allow for testing.

Information value assessment may derive from other aspects of information quantity assessment. The distinction between foreknowledge and discovery makes this clearer[51]. Foreknowledge

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[51] Hirschleifer '71.

describes advance information about states of the world, such as the future price of a stock. All that is required to confirm foreknowledge is for sufficient time to pass until the world reveals the accuracy of the insight. Discovery, on the other hand, describes a recognition of information that possibly already exists but which remains hidden from view. Work is required to extract discoveries such as the properties of materials or physical laws but nature will not normally reveal them. This distinction roughly parallels the distinction between description and principle. Descriptions represent observations that the state of the world has revealed. Principles have required expended effort to uncover them. Discoveries and principles have the added advantage that they are useful for prediction. These principles may indicate an underlying relationship or a strong correlation which may be exploited by creating foreknowledge, or a future description. Past or present description cannot yield foreknowledge. Only through application of the underlying principle can foreknowledge be obtained. To this extent, principle is likely to be more useful than description. Whether the price reflects this, however, is for the market to decide.

This returns the debate over information frameworks to the Phone Book/Physics Text test. Does IQA have anything useful to say respecting the relative advantages of each body of information? For comparisons of the quantities and types of information, the answer is yes. The physics text contains a much higher percentage of principle information than the phone book, which is purely description. The textbook may also contain instructions on the application of its principles as well as historical facts. In this sense, the physics text is more diverse in the classes of information it contains. The phone book, however, contains a greater number of units of description, due to the density of a chart format relative to natural language. In absolute terms, the physics text contains more process and principle information; the phone book contains more description. The relative advantage or value of these two types of information will depend on the application.

Several of the IQA attributes offer further axes of comparison. Although at the time of first printing, each volume may have been equally *accurate*, the decay rate of the phone book is higher as the residents of a community move. Information in the phone book is therefore less durable. Information in the phone book is also less *complete* but more *exhaustive*. It contains only three categories of information -- name, address, and telephone number -- but each dimension contains a nearly exhaustive listing of the telephone information in an area. In contrast, the physics text will span a much larger set of categories but probably not exhaust the material in each of its categories as thoroughly as a phone book exhausts the names in a city. The *redundancy* of each information source will probably be similar. Neither will contain much repeat information. Comparisons of *novelty* will depend on the number of owners of the respective texts.

Which should cost more? Here, the answer depends on the market's relative preferences for description, instruction, and principle as well as the attributes associated with each. The market for information represents an average of the total demand for uses of information. Depending on market needs at various points in time, the relative prices of each class will change. Then, even if the market does not change, the application may. Novelty is a critical virtue in selling the market a patent, which is process information. Novelty, however, is a liability in selling the market a copyrighted computer operating system, which is also process information. High scores on an attribute do not necessarily equate with price. An information quantity assessment merely provides axes for making comparisons.

In general, tests of information similarity reveal relative value for intra-class comparisons only. Along any particular axis, the framework will define relative values. Across axes, the relationship breaks down and comparisons are not instructive. What are tests of similarity? For description, comparative tests apply to identical or isomorphic dimensions even if the data are not identical or isomorphic. If two descriptions pertain to the same data elements, for example street address and zip code, then it is possible to draw meaningful comparisons. This is a broader concept than Blackwell's criterion since one data set need not be a subset of (or stochastic transformation of) another. For processes, tests of similarity depend on identical initial and final states. Since the beginning and ending conditions are identical, the route becomes the issue of importance. Evaluations of relative value may distinguish the number of steps, the time of the instructions, the yield, and the costs of each step. For principles, comparative tests also apply to the dimensions. Estimates of relative value will rely on completeness and the level of confidence (predictive power).

CHAPTER 4

> When establishment of [the] mapping of real things into the commodities of theory is not so easy, theory has very little to say. -- *C. B. McGuire*

> Don't tell me how hard you work. Tell me how much you get done. -- *James J. Ling*

Potential Information Use in the Air Cargo Industry

The IQA framework was designed in the hopes that it might prove both theoretically and managerially useful. In order to test its applicability, IQA concepts are used to approach several problems enumerated below. The problems are representative of broader issues but are nominally set in the air cargo industry due to its heavy reliance on information technologies and its continuous study of its own processing capabilities. The net margins on air cargo tend to be quite low, typically pennies per package. This fact leads industry competitors to seek ways of differentiating their products and of increasing delivery efficiencies. Some of these problems, such as process redesign, are longstanding issues in any managerial setting, while others, such as massive data management, are fairly specific to large consumer companies. In some instances, IQA offers special advantages over existing management techniques due to its treatment of information as a commodity. In other cases, it represents an alternative method for expediting a given problem using no additional overhead. The advantage of the new framework is that the same framework has a large variety of applications.

Information Quantity Assessment provides a framework for defining information as an asset or commodity in order manage information actively. IQA seeks to ultimately increase a company's profitability and competitiveness by supplying the means to quantify information for use in accounting and strategic planning. Through the "productization" of information, IQA encourages the creation of new information products as sources of incremental income. Using the framework will also allow managers to evaluate the efficiencies of a company's information, and realize cost savings through reduced waste and decreased redundancy.

Problem 1: Creating Information Products

UPS employs 62,000 drivers and delivers on the order of 11 million packages per day. Scheduling and routing delivery poses an important problem. Small improvements in scheduled dropoff and pickup plans can offer seven figure savings in fuel and direct labor costs. To tackle routing and scheduling, UPS has invested in Roadnet, a separate company engaged in the process of creating digitized maps of all cities in the United States. Eventually, Roadnet hopes to track streetlevel information to the point of knowing the duration of individual traffic signals. Can UPS and Roadnet create information products based on the large quantity of data collected?

A proposal to achieve this might begin by dividing the information into classes of the IQA framework, partitioning on the basis of description, instruction, and principle. One possible relational database arrangement of the descriptive information is shown in Figure 4.1.

Figure 4.1 -- A relational DB framework captures Roadnet data.

	Start	End	Capacity	Speed	Distance	...
Street 1-1						
Street 1-2						
Street 1-3						
Street 2-1						
Street 2-2						
...						

Each street segment is represented by a single relation. Each relation represents one unit of description.[52] Based on this configuration, it is possible to devise an efficient simplex algorithm to span the network of streets using either time or distance as the cost function. The number of instructions in the network algorithm gives its quantity. Further, Roadnet may gather and analyze additional information to provide average flows and average numbers of accidents. These characterizations provide principle information useful for predicting traffic patterns. Products based on these classes may take several forms.

Description: Basic descriptive data may be sold in two forms. Roadnet might sell the database or it might use the database to construct extremely high precision maps. Careful copyright protection would be necessary to protect from unauthorized sale and distribution of data once it had been sold. The markets might include real estate, cartography, and local government.

[52]"Distance"may be calculated from the start and end points, but might remain a separate domain in the database for reasons of efficiency. With one dependent domain, completeness remains at four.

Instruction: Because it is easier to maintain control of processes, instruction information may either be sold or rented. Renting would involve allowing users to access the network software to plot specific paths. Alternatively, by running the software, it would be possible to sell single specific sets of directions on a request basis. Also, software embodying the algorithm might be sold. The market for these services is quite large, involving any company that makes deliveries, as well as police and emergency vehicle drivers, who value the most expedient route.

Principle: The characterization information concerning average flow and average accident rates is primarily useful for planning and prediction. This information could be sold to city planners, departments of transportation, and actuaries at insurance companies. If information is collected down to the stoplight level, it might be possible to sell consulting services to improve traffic flow.

This section is not intended to judge the relative merits of any one product but rather is intended to show the feasibility of creating such products once information has been collected. It may be the case that the sale of information offers substantially greater income potential than the potential economic advantage of keeping information proprietary.[53]

Problem 2: Pricing Strategies

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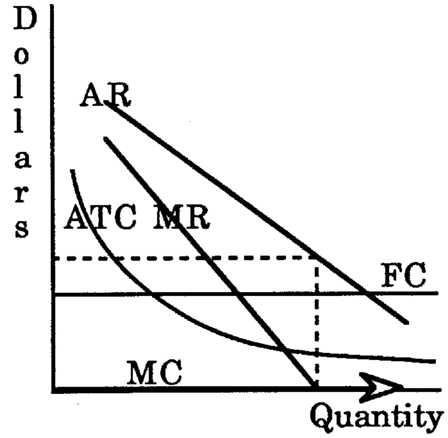
[53]SIC directories show more than two dozen *types* of companies that make deliveries. If each type were willing to pay one tenth the value of its own savings to a seller of routing schedules, the seller is likely to earn considerably more than its own savings would be worth.

Given an information product, pricing strategies must be developed for recovering the information investment. Microeconomics determines market prices through the combination of supply curves, which generally increase with price, and demand curves, which generally decrease with price. The unusual nature of information, however, introduces new dimensions into these calculations.

Standard economic practice is to sell that quantity of product which equates marginal cost with marginal revenue. If marginal revenue exceeds marginal cost then there is an incentive to increase gains by selling more, but if marginal revenue falls short of marginal cost then there is incentive to cut losses by selling less. The point where these two curves meet also determines the price. For information, however, the marginal cost is always zero. After information is sold, it remains available to sell again and again. Zero marginal cost implies that long run equilibrium in a competitive market occurs when information is free. If this were always the case, underinvestment in the production of information would virtually be guaranteed. The insight cautions potential suppliers of information; businesses must not enter into information markets where the supply of information conforms to the supply in competitive markets.

Competitive market assumptions include, among others, that products are uniform and that there are numerous suppliers, neither of which are true for information markets. Copyrights and restricted access to sources both act to ensure monopoly power. This in turn generates more than standard economic profits. The monopolist's profitability looks markedly improved.

Figure 4.2
Considerable profits are possible for the information monopolist.



AR -- Average Revenue (the demand curve)
ATC -- Average Total Cost
FC -- Fixed Cost
MC -- Marginal Cost
MR -- Marginal Revenue
Dashed line indicates price and quantity equilibria.

In this figure, the amount of information supplied conforms to the point at which the marginal cost intersects the marginal revenue but the price charged per unit is given by the demand curve AR. For competitive markets the demand curve and the marginal revenue curve are the same. The monopolist, however, enjoys net profit governed by the difference between Average Revenue and Average Total Cost. Setting the price is then a matter of determining what quantity of sales sets marginal revenue equal to zero, then plugging this quantity in to the demand function. For example, assuming demand[54] is 1000 - 50Q then

$$\text{Total Revenue} = PQ = (1000 - 50Q)Q$$

$$\partial(TR)/\partial Q = 1000 - 100Q = 0$$

$$Q = 10 \Rightarrow P = 1000 - 50(10) = \$500 \text{ per unit.}$$

[54]Actual demand must, of course, be determined empirically.

Five thousand then gives the total revenues of a firm facing this demand curve.[55] Much more interesting behavior emerges if the demand curve is multidimensional, for example:

$$P = \alpha(\textbf{Redundancy}) + \beta(\textbf{Completeness}) + \rho(\textbf{Exhaustiveness}) + \gamma(\textbf{Novelty}) + \delta(\textbf{Accuracy}) + \lambda(\textbf{Time}) + \chi(\textbf{Interest}) + \psi(\textbf{Relevance}) + \mu(\textbf{Quantity})$$

Using this formula, one can determine the optimal level of any particular attribute, and the subsequent total price, by equating the partial derivative of the total revenue function with the partial derivative of the total cost function for that attribute. To determine the most profitable level of accuracy, for example, set $\partial(TR)/\partial \text{Accuracy} = \partial(TC)/\partial \text{Accuracy}$. This level of accuracy is then fixed for use in determining the total price. Although the previous example showed that the marginal cost of producing an identical unit of information is zero, this is not necessarily the case for new units of information or for the marginal costs of the attributes. The accuracy of a mailing list, for example, deteriorates over time indicating that there are likely to be positive costs associated with maintaining a specified level of accuracy. Importantly, the utilities for each attribute (the demand curves) will vary with the decision context although the quantities of each attribute (the supply curves) will remain constant, as they should.

Specific situations will vary greatly and interesting patterns of behavior can result. The demand for operating system software, which is largely process information, increases inversely with novelty. Purchasers of operating systems wish to standardize their software in order to increase the number of potential packages that will run on their

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[55]Selling 11 units rather than 10 drops the price to 450 and the total sales to 4950.

computers. For the novelty attribute, this creates a positively sloped demand curve as buyers are willing to pay more for a package that has gained widespread acceptance. Again, as the normative theories suggest, price but not quantity will depend on the specific context.

Problem 3: Data Management -- Handling 4 terabytes of descriptive data.

Over the course of a delivery, each package generates data about several factors. These may include but are not limited to a source, a destination, routes, time on route, human and machine handlers, insurance, and dimensions. Eleven million packages a day force data to accumulate rapidly. The magnitude of this data raises the question of how it might be useful strategically.

It has been suggested [Gorry and Scott-Morton '71] that managerial activity at the operational control level differs substantially from managerial activity at the level of strategic planning. Different roles result in different information needs. Operational control concerns the execution of specific tasks and requires specific accurate and immediate data. At an intermediate level, management control deals with efficient use and allocation of resources. This requires a higher level of aggregation and is broader in scope. Strategic planning concerns the setting of policy guidelines and company objectives. It, in turn, requires the highest level of information aggregation; it tends to rely more on forecasts, and much of this information must come from outside the corporation. Figure 4.3 summarizes the spectrum of information needs.

Figure 4.3 -- Managers' information needs vary with function[56].

Information Characteristic	Operational Control	Managerial Control	Strategic Planning
Source	Largely Internal ⟵⟶ Largely External		
Scope	Well Defined, Narrow ⟵⟶ Very Wide		
Level of Aggregation	Detailed ⟵⟶ Aggregate		
Time Horizon	Historical ⟵⟶ Future		
Time Frame	Highly Current ⟵⟶ Old		
Required Accuracy	High ⟵⟶ Low		
Frequency of Use	Very Frequent ⟵⟶ Infrequent		

The difference in the classes of information from the IQA framework provide aspects of this flexibility. At the operational control level, descriptive data whose time is recent can be used in the sorting, scheduling, and routing of packages. Higher level managers would find raw data to be minimally useful. However, conveying to them data that has already been summarized through statistical methods and captured in principle information is quite helpful. Capacity planning may rely on destinations that have consistently grown in average demand. Routes that often lose packages may be targeted for upgrading. Formulae may be calculated for the elasticity of demand which can substantially increase revenues. These formulae may lead to price discrimination packages based on time of year and location as well as size and weight. These summary statistics are useful in providing decision support. After operational control has finished with data, it seems more practical to keep statistical summaries and trend information online than to face the expense of making all data available to all levels of management.

As noted by Gorry and Scott-Morton, forecasting also represents one of the primary activities of middle and upper level management.

[56]Gorry, Anthony and Michael Scott-Morton; "A Framework for Management Information Systems;" *Sloan Management Review,* Fall 1971; Cambridge, MA; p. 59.

The definition of principle information, which includes characterizations and correlations (formulae) makes this possible. From an initial set of descriptions it is feasible to calculate the relationship of customers to price and of productivity to customers. Then from the current conditions, it is possible to project into the future what the likely activity level of a given variable will be. The 'completeness' of a principle gives the number of factors on which a particular forecast relies while the 'accuracy' of the principle provides the confidence level with which one may anticipate the result. Formulae useful for prediction may appear in any number of locations -- one can conceive of predicting economic recessions based on the call volume of attorneys' offices. The confidence level determines whether such correlations are valid. No set of equations may anticipate all possible exogenous shocks to a system but a sufficiently large set of equations may provide a helpful approximation of the market conditions at a future date.

The magnitude of descriptive data highlights the need for careful management and information indices along the lines of solvency, efficiency, and profitability. By itself the raw data indicates that information waste is likely to be low but that the relative proportion of descriptive data may be too high. A company with a great deal of unanalyzed data may be solvent in descriptions but insolvent in instructions or principles. The rate of generation also suggests high profitability but again this is only on one area of information. Much of the data needs to be converted to principle data detailing the trends of the operation and the formulae which govern its success. Much of it needs also to be used in the redesign of existing procedures. Additional treatment of this topic follows under process enhancement.

Problem 4: Process Enhancement

> "We know the best way to approach a truck (the right foot first) and the best place to carry one's keys (on the right pinky)."
> -- *Frank Erbrick, Sr. VP of IS, United Parcel Service*

Large scale repetitive operations, as in the case of the air cargo delivery business, offer great opportunities for cost savings if even small but continuous improvements can be introduced into routine procedures. As noted in the routing plans, minutes shaved from the standard procedures can save millions of dollars. UPS is so conscious of this fact that they have devised innovative methods of package handling to save a few seconds. To locate the label on a package, most people will pick up the box placing their hands on the faces of two opposing sides, then rotate the box several times until the label comes into view. This may require up to three rotations of the box to examine all six faces, assuming at least two faces are always visible. At UPS the procedure is different. Package handlers are trained to grasp a box by opposing (diagonal) corners and with one motion spin the box along this axis until the label comes into view. In a separate instance, UPS has devised mechanisms for servicing its fleet in half the time of published industry standards. By analyzing the service process, UPS has designed alternate and superior task planning and work area layout. The question arises, is it possible to use the proposed information framework to assist with and improve the redesign of standard processes to conserve time and effort?

To enable an information processor such as a computer to solve problems requires specifying both a task and a means of task resolution. Different types of information from the IQA framework may be used to specify the task as well as the procedure for its solution. A task order describes the initial conditions and the final conditions. It is essential that this description of a task be declarative rather than procedural -- the task order must describe the desired result without indicating how to achieve it. A procedural method of specifying the task would interfere with the exploration of alternative procedures or solutions. To avoid an order that dictates a single, self-fulfilling solution, the task order can be defined using *description* information to provide an initial state and the desired final state. Task resolution then proceeds as the information processor searches through the available *instructions* to discover a path from the initial configuration to the final. It is essential that the search consider multiple instructions for accomplishing the same task. If only one procedure is specified, an alternative, more expedient procedure cannot be found. Given several alternative processes, however, evaluation proceeds according to the proposed set of measures (i.e. number of steps) and attributes (i.e. accuracy, time, completeness, etc). The final process selected will be that which provides the greatest value, based on the units and attributes most pertinent to the application.

A simple stylized model illustrates. If an air cargo company were to enter the packaging business in a move toward vertical integration, one potential task might be the design of a rapid packaging process which minimized resource use but which passed a box crush test. An initial state of the world is given by ((resource*A* units 11) (resource*B* units 2) (resource*C* units 2)) but a final state ((product*D* units 1)) is desired. Notice that this description places no requirements on the amounts of resources *A*,*B* and *C* upon completion. A more detailed and confining final state might have been ((resource*A* units 3) (resource*B* units 0) (resource*C* units 2) (product*D* units 1)). Now suppose the task is to create a product -- a reinforced package which consumes various amounts of resources *A*, *B* and *C* (perhaps paper fiber, glue, and plastic) and which must pass a crush test of a little more than 24 lbs. The instructions on hand include {wrapping, tying with string, taping, adding newspaper, adding styrofoam, and reboxing}. Further, searching has revealed five processes which use these instructions and resources to produce roughly similar results. Assume also that the cost of materials (resources) is negligible compared to the cost of labor (instructions), which is represented as {1, 1, 2, 3, 4, 5}, respectively. The processes' resource use, operational requirements, and attributes are given as follows:

Figure 4.4 -- Process evaluation must consider multiple factors

	Resource Requirements			Operational Requirements						Attribute Measurement		
	A	B	C	Wrap	Tie	Tape	News	Styro	Rebox	Cost	Time	Accuracy
Process 1	12			11						11	11	98%
Process 2	2	2	1		1	1	1	1		10	4	100%
Process 3	2	1	1		1		1	1		8	3	100%
Process 4	3	1				3				6	3	98%
Process 5	1	1	1			2				4	2	77%
Process 6	2					1			1	7	2	98%

Cost = Operational Cost * Operational Requirements. (respective costs are 1, 1, 2, 3, 4, 5)
Time = Total number of Steps (Instructions).
Accuracy = Distance from target of $24^1/_3$ lbs. (measured independently)

Selecting the most desirable process depends the utility function and environmental constraints acting on the manager's set of choices. The least expensive process, P5, is also the least accurate. The most accurate processes, P2 and P3, are among the most costly. The only process which may be rejected out of hand is P2 since none of its attributes exceed those of P3 and it also uses both more resources (B) and extra technology (taping). An older company well endowed with resource A but which is limited to the cheap wrapping technology might still prefer P1 despite its cost[57]. The fastest process, P6, also uses the most expensive reboxing technology. Although only a handful of instruction attributes are used, the quantities provided together with a utility function define the constraints and the objective function for a simplex algorithm. The information attributes concerning the process (its steps, its accuracy, its time, etc.) are fixed for all decision problems. However, the utilities of each process will change with the user, as they should. Solving the simplex algorithm to match an information process to a specific user is then straightforward.

Simplifying this problem still further will illustrate the means for developing the six independent processes. Assume that the resources are not paper fiber, glue, and plastic but are instead the digits 2, 3, and 5. Further assume that the instructions are not labor or technologies but instead +, -, *, /, ^, and !. The reinterpreted chart is shown as Figure 4.5.

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[57]The initial conditions would preclude this process since only 11 units of A are available.

Figure 4.5 -- Reinterpreted process chart.

	Resource Requirements			Operational Requirements						Attribute Measurement		
	2	3	5	+	-	*	/	^	!	Cost	Time	Accuracy
Process 1	12			11						11	11	98%
Process 2	2	2	1		1	1	1	1		10	4	100%
Process 3	2	1	1		1		1	1		8	3	100%
Process 4	3	1				3				6	3	98%
Process 5	1	1	1			2				4	2	77%
Process 6	2					1			1	7	2	98%

Cost = Operational Cost * Operational Requirements. (respective costs are 1, 1, 2, 3, 4, 5)
Time = Total number of Steps (Instructions).
Accuracy = Distance from target of $24^1/_3$ lbs. (measured independently)

Using the process definition of "relevance" as the degree to which an instruction moves an initial description towards a final description, a process designer might arbitrarily select instructions and apply them to conceptual states in an effort to produce a final state. An instruction with a high level of relevance produces a result closer to a final state than an instruction with low relevance. The process terminates[58] when its distance from the desired state is sufficiently small. In this example, the initial state is a supply of digits, the instructions are mathematical, and the final goal is a strength of $24^1/_3$. Processes 1 through 6, having been developed through arbitrary search, may now be revealed to be:

		Cost	Time	Acc[59]
Process 1:	2+2+2+2+2+2+2+2+2+2+2+2 = 24	11	11	98.6%
Process 2:	[(3*5^2)-2]/3 = 24.33	10	4	100%
Process 3:	5^2-2/3 = 24.33	8	3	100%
Process 4:	3*2*2*2 = 24	6	3	98.6%
Process 5:	2*3*5 = 30	4	2	77%
Process 6:	(2*2)! = 24	7	2	98.6%

[58]If it halts. It is certainly possible to define tasks which no arbitrary set of operators can achieve.
[59]Accuracy is $|\text{target} - \text{actual}|/\text{target}$.

Process redesign need not stop here, however, as the processes have not been fully optimized. For each process in which an instruction does not conflict with another instruction, those steps may be performed in parallel rather than in serial. In order for two instructions to avoid conflict, they must meet two standard conditions. They must not require the same resources (to avoid deadlock), and the final result must be independent of the (arbitrary) order in which the instructions fire. Addition and multiplication, for example, cannot generally be performed in parallel since the order of the operations affects the result, for example, (5+2)*3 ≠ 5+(2*3). Optimized processes reduce the time associated with each process in the following manner:

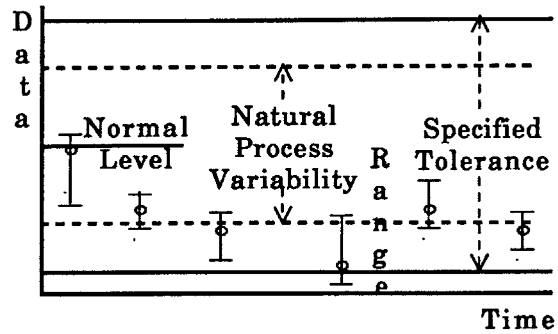
	"Original Time"	"New Time"
Process 1: 2+2+2+2+2+2+2+2+2+2+2+2 =24	11	$\log_2(11)\approx 4$
Process 2: [(3*5^2)-2]/3 = 24.33	4	4
Process 3: 5^2-2/3 = 24.33	3	2
Process 4: 3*2*2*2 = 24	3	$\log_2(3)\approx 2$
Process 5: 2*3*5 = 30	2	2
Process 6: (2*2)! = 24	2	2

A further application of the IQA framework to process enhancement is in the area of statistical process control (SPC). Maintaining quality standards in either products or services frequently involves statistical sampling of output and error correction based on the results.[60] SPC requires businesses to set quality targets and to define measurable attributes which indicate compliance. Statistical sampling

[60]Juran's Quality Control Handbook covered this subject in 1954 and SPC is covered in standard textbooks of operations management. See for example J. M. Juran, Ed.; *Quality Control Handbook*; New York: McGraw-Hill;© 1971 or John McClain and L. Joseph Thomas; *Operations Management*, Second Ed.; Englewood Cliffs, NJ: Prentice-Hall © 1985; Ch. 16.

then places actual performance on a graph from which trends and cycles can be detected, often leading to the correction of anticipated rather than realized problems. Statistical average and range charts, such as the following, describe actual performance.

Figure 4.6 -- SPC Chart describes output quality.



In this chart, error correction proceeds from samples that fall outside the proscribed ranges, from cycles that may develop, and from sample trends showing a problem is likely to occur. The vertical bars indicate the range of a sample and the circle gives the average. Descriptive information is the result of an actual product sampling. The statistical summary giving mean, range, and standard deviation for the description is principle information. With little or no adaptation, the IQA framework may be used for statistical process control.

CHAPTER 5

> Life is the art of drawing sufficient conclusions from insufficient premises. -- *Samuel Butler*

> There are two things which I am confident I can do very well: one is an introduction to any literary work, stating what it is to contain, and how it should be executed in the most perfect manner; the other is a conclusion, shewing from various causes why the execution has not been equal to what the author promised to himself and to the public.
> -- *Samuel Johnson*

Answers to Principal Questions

The first chapter posed five questions which affect the characterization and management of information. The purpose of this section is to initiate a response. Concrete answers to all five will require additional research but the IQA framework outlined above provides a useful platform from which to launch further investigation.

How does one measure information? Is there an information currency?

One measures information by ascribing objectively measurable units to its intrinsic features. A recurring theme throughout this thesis is that measuring information through extrinsic features provides a non-transferrable value only. Information, like other products, must be treated as a commodity which may be passed between owners. Measurement proceeds from intrinsic features to objective measures which may be used by the marketplace. Quantity determines relative values, while the market determines an absolute price.

Selecting any information currency is somewhat arbitrary, like choosing the metric system over the English system of units. Settling upon a quantifiable system of units defines the currency. The currency defined for description is relations, for processes it is instructions, and for principles it is characterizations (e.g. range) or formulae.

Storage media presents a common impediment to measuring information. The position taken here is that while difficulties in transferring between media will affect price, these difficulties do not affect the intrinsic quantity which remains independent of media.

How might one classify information and what are its relevant attributes?

The system proposed here breaks information into description, instruction, and principle. Each class has a different purpose. Description provides a means of characterizing states of the world. Instruction provides a goal oriented mechanism for changing states of the world. Principle provides a guideline for choosing which new descriptions are preferable and which processes will achieve them. These guidelines are in the form of correlations between states. Importantly, principle never depends on causality, only on statistical correlation. The purpose underlying the use of statistics is to make the system as mechanizable as possible given that machines cannot generally deal with causality.

The defined attributes include redundancy, completeness, exhaustiveness, novelty, accuracy, time, interest, and relevance. Each attribute carries a specific numeric index which allows for comparisons among groups of information. The units differ according to the axis of comparison.

What information presents the most worthwhile investment opportunity and on what occasions should one buy, sell, or trade information?

The decision to invest in information relies on the potential for creating value -- obtaining accurate and relevant descriptions, filling in incomplete processes, and discovering fundamental principles. According to standard economic practice, resource allocation should equate marginal revenue with marginal cost. Investment should increase along dimensions where marginal revenue exceeds marginal cost and it should decrease along dimensions where marginal revenue falls short of marginal cost. The dimensions for investment are those of the proposed framework. In other words, investment in the accuracy of a description, for example, should continue until the increased accuracy no longer produces additional return. Japanese manufacturers are committed to constant process enhancement and enjoy the competitive advantages this produces.

What frameworks will indicate the data that is captured or not captured by a corporation?

Existing literature contains numerous frameworks for managerial uses of and requirements for information.[61] These tend toward applied information technology approaches which are managerially more practical than the theoretical decision valuation

[61]Gorry and Scott-Morton, Keen and Scott-Morton, Bullen and Rockart, Zmud.

approaches. The IQA framework generally adapts well to the applied frameworks as in the case of the Gorry and Scott-Morton proposal.

Are there tools to measure information management efficiency?

The proposed tools for identifying problems and opportunities are the information estimates of solvency, efficiency, and profitability. Solvency measures the amount of information available. Efficiency measures the leverage of information output relative to information input. Profitability measures the information generation rate. These may inform management of information waste and of missing information. They may indicate stagnation or overemphasis on one type of information or point out deficiencies to come. Much work remains to be done, however, to devise information metrics.

Conclusions

The information framework detailed in the course of this thesis has endorsed an alternative approach to measuring information. The primary difference is expressed as the distinction between an information *quantity* assessment and an information *value* assessment. A quantity assessment has the advantage that objective measures transport across contexts and enable information markets to be established. Under IQA, information receives the status of a true commodity. Estimates of value may proceed, as before, to calculate incremental gain based on the particular decision and the data available. The utility to a decision maker has not changed, although a decision maker now possesses more specific criteria on what, how much, and which type of information to purchase. He may also have indices of his information management skill. Quantity measurements therefore do not replace value measurements but complement the set of available tools.

Measurement proceeds from the introduction of information classes. Disaggregating information by type recognizes that differences exist in its use and application. This improves considerably on present approaches which treat information as a monolithic and uniform substance. Where differences exist in information classes, a taxonomy makes it possible to make stronger statements about elements of a particular class. Scope limitations then allow one to focus on the information relevant to a specific problem: choosing, making a prediction, enhancing a process, or buying a database, etc.

The information classes also tell an information manager (including a computer) details about the semantics of the information by indicating how such information is used. Existing theories typically measure information based solely on contextual value. How the information would be applied to add value is never considered. IQA, on the other hand, enumerates information based on its function.

From the classes of information arise differences in the attributes of each class. These attributes provide numerical axes for comparing distinct sets of information in an effort to establish their relative values. Tests of similarity improve upon the power of Blackwell's theorems by permitting comparisons between transposable *categories* of data in addition to transposable data. Differences in the measurement of attributes by class also make it simpler to provide specific numeric units. A measure of "completeness," for example, is difficult if information is treated as a uniform substance.

The objectivity of units and attributes in IQA may lead to improved understanding of more subjective interpretations of value. With precise definitions, "obsolescence", "novelty", and "durability" become objectively quantifiable. Subjective value differences arising from imprecise definitions or disagreement over points of emphasis may disappear once terminology and methods are duly clarified.

Methods for assessing information also adapt to managerial information systems frameworks such as that proposed by Gorry and Scott-Morton. Managerial activity covers contexts much more diverse than single instances of exerised choice. In fact, managers spend considerable time looking for problems, looking for options, and learning from experience. IQA operates across contexts and it can provide heuristic approximations of managerial effectiveness as well. In contrast, management based on prior probabilities is extremely difficult.

The potential for improving strategic planning through Information Quantity Assessment is great. Active management of a company's information resources through IQA could, for example, support executives in determining directions for research and development functions, assess the health of a company's information versus the competition's, predict upcoming obsolescence in time to design a response, and improve on other strategic analyses currently performed on an intuitive basis. Potentially, information indicators may predict a company's cash indicators in advance, providing more time to respond.

Property, plant, and equipment possess a concreteness that information will find hard to match. When information becomes clearly understood, it may well provide the basis for a large and successful information market. While the measures proposed here lack the precision of cash, it is hoped that steps in this direction will provide the tools to fold information into assessments of corporate value with a higher degree of precision than currently exists. The tools provided by IQA treat information as a commodity and help to quantify information as an asset. This may be a distinguishing factor in separating corporate market value from corporate book value. This represents a novel approach to assessing the value of a critical intangible asset. Were it possible to capitalize and depreciate an information investment, the costs would decline significantly. With a certain degree of optimism, one hopes that this will eventually be the case.

APPENDIX A

This section derives the information economics function for the value of an information system (found on page 15). The model of the decision theoretic system is repeated below for ease of reference.

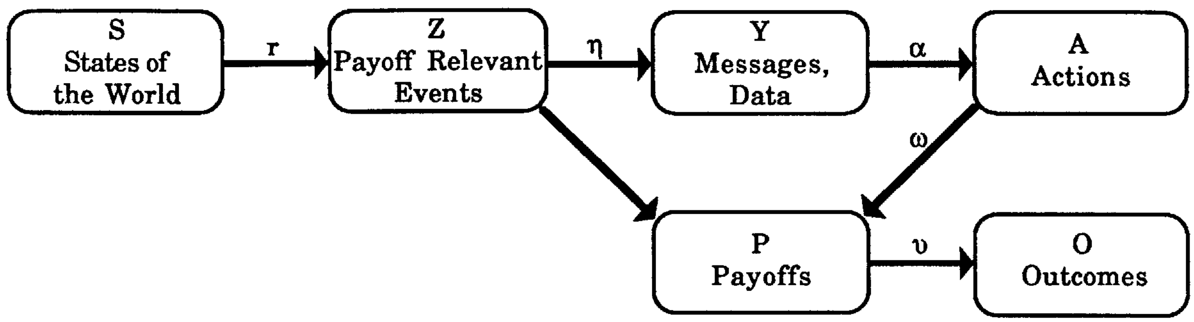


Figure A.1 -- Information may be characterized by its use to effect payoffs.[62]

S = Universal set of states of the world.	r = A partitioning which distinguishes only those states affecting payoffs.
Z = Set of payoff-relevant events.	η = An information association relating events and messages.
Y = Set of messages (Information) about the state of the world	α = A decision function (rule) relating events and messages.
A = Set of possible actions.	ω = An outcome function mapping actions into effects.
O = Set of possible outcomes (one outcome for each Z, A pair)	υ = A utility function relating a payoff (a p_j in P) with each outcome (o_i in O).
P = Set of payoffs (associated with each outcome).	

[62]Diagram adapted from Mock.

The best choice of decision function is that which results in the greatest possible return to the decision maker based on his preferences. This is the largest possible value of $\upsilon(\omega(s,a))$. In other words, given a set of states s and a set of actions a, perform that action (execute ω) whose outcome provides the greatest benefit (given by υ).

Each collection of states is complete and the members are mutually exclusive. This implies that members fall within a probability distribution $\phi(x)$ such that $\Sigma\phi(x) = 1$. Consequently, for any particular state s the *expected* return is given by $\upsilon(\omega(s,a))\phi(s)$ and the total for all states by

$$\sum_{s} \upsilon[\omega[s, a]]\phi(s)$$

The decision maker, however, will be basing his actions on the signals provided by the information system. In this case, the equivalence $\alpha(y)=a$ maps from signals to actions. Knowing only the signals y, the decision maker will not necessarily know the prior probability $\phi(s)$ and so must use Bayes theorem to substitute $\phi(s \mid y)\phi(y)$. As a result, grouping the states according to all signals that might correspond to them and substituting gives

$$\sum_{y}\sum_{s} \upsilon[\omega[s, \alpha(y)]]\phi(s \mid y)\phi(y)$$

for the gross realizable value obtained through use of an information system.[63] For the net value, one must subtract the impact

[63]The complete substitution would be $\sum_{y}\sum_{s} \upsilon[\omega[s,\alpha(\eta(s))]]\phi(s \mid \eta(s))\phi(\eta(s))$

of decisions made without the benefit of the information system resulting in

$$\sum_{y}\sum_{s}\upsilon[\omega[s,\ \alpha(y)]]\phi(s\,|\,y)\phi(y)\ -\ \sum_{s}\upsilon[\omega[s,a]]\phi(s)$$

APPENDIX B

Given a unique event[64] ***E***, its probability of occurrence p must fall between 0 and 1. But how "informative" is a reliable message stating that ***E*** has occurred? If the probability of occurrence is high, i.e. $p = .99$, then news of the event is not surprising. On the other hand, if the probability is low, or $p = .05$, the news is significant and highly informative. This suggests that the amount of information $q(p)$ conveyed by such a message increases with its surprise. A function exhibiting this feature is:

$$q(p) = -\log(p)$$

Although other monotonically increasing functions will work, this form has gained widespread acceptance [Shannon and Weaver '49, Lev '68, Kinchin '57, Ronen and Falk '73] due to its additive properties. These properties allow one to sum independent probabilities to previously calculated results without interference. The function derives from the Second Law of Thermodynamics which measures uncertainty or disorder.

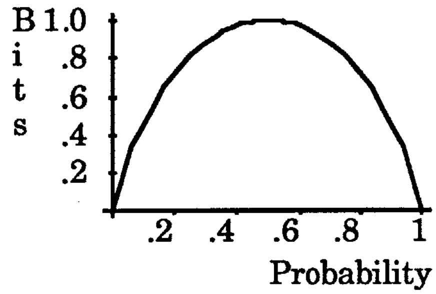
The probability of receiving a message concerning E will occur with probability p so that the expected value of information is $-p \cdot \log(p)$. The same message describing the two state event ***E*** also describes the event ***not E*** with probability $1-p$. The total information is therefore:

$$Q = p \cdot q(p) + (1-p) \cdot q(1-p) = -p \cdot \log(p) - (1-p) \cdot \log(1-p)$$

[64]The following explanation is developed in Lev '68.

This gives the entropy function for a discrete event. For n equiprobable events, this generalizes to $-\Sigma_{i=1}\, p_i.log(p_i)$ for i from 1 to n. If two is used as the base of the logarithm, the discrete entropy function has a range from 0 to 1, yielding a quantity of information which is measured in bits. Entropy function values are shown below.

Figure B.1 -- Entropy function values



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